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CMHC

MOISTURE SOURCE STRENGTH:

MEASUREMENTS IN SELECTED CANADIAN CITIES

Prepared for

Project Implementation Division
Policy, Research and Programs
Canada Mortgage and Housing
Corporation

by

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June 1987

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Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

DISCLAIMER

This study was conducted by Appin Associates for Canada Mortgage and Housing Corporation under Part V of the National Housing Act. The analysis, interpretations and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

CMHC SUMMARY

Background:

The rates of moisture generation and removal are major factors in predicting potential moisture related problems in housing. A procedure developed by CMHC and NRC to determine the point-in-time moisture source strength within a dwelling was field tested in 1984 on houses in Ontario and British Columbia.

Objectives:

To broaden the base of moisture source strength data, and to further verify test procedures, by undertaking moisture source strength tests in the Prairie and Atlantic regions.

Methodology:

The Consultant carried out a total of 35 moisture source strength tests in 22 houses in Regina, Winnipeg, Halifax and St. John's, representing a range of age and type of construction. One house in each city was selected for multiple testing.

Conclusions:

Moisture source strength testing represents a "snapshot" of conditions within a house, and therefore cannot provide a complete assessment of the potential for moisture problems.

Multiple testing produced widely varying results, especially in older, leakier houses. Test results indicated that the quantities of moisture being processed by typcial houses are often much higher than is conventionally expected.

The small sample size did not allow definitive conclusions to be drawn regarding climatic or geographic differences, the distribution of moisture source strength floor by floor, or the effects of storage.

In attempting to correlate moisture source strength findings with the extent of moisture problems, the Consultant noted that the internal moisture source strength from internal sources, ground sources and storage (IMSS) often equals or exceeds the moisture source strength from ventilation (VMSS).

Recommendations:

The Consultant has recommended simplifying the test procedures in order to assist in the diagnosing and retrofitting of moisture troubled units.

Future work in moisture source strength testing will need to incorporate other specific house data, such as airtightness (ELA) and shielding coefficients for wind and temperature.

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GLOSSARY OF TERMS

ACR -Air Change Rate (Litres/second)

AHi -Absolute Humidity Ratio Indoors (Kg Water Vapour per Kg Dry Air)

AHo -Absolute Humidity Ratio Outdoors (Kg Water Vapour per Kg Dry Air)

IMSS -Internal Moisture Source Strength (Kg/day)

RHib -Relative Humidity (beside basement)

Tin -Inside Temperature (^{o}C)

TMSS -Total Moisture Source Strength (Kg/day)

Tout -Outside Temperature (^{o}C)

VMSS -Ventilation Moisture Source Strength (Kg/day)

EXECUTIVE SUMMARY

A. Background

This CMHC project was undertaken by Appin Associates (Winnipeg) with assistance from Eneraction Resources Ltd (Regina), Scanada Consultants Ltd. (Ottawa), Provincial Consultants (St. John's) and Pearson Associates (Halifax) to obtain a better understanding of the factors influencing moisture movement in houses and to check out test procedures. A total of 37 tests were carried out on 22 houses in four cities - Regina, Winnipeg, Halifax and St. John's. In each city one house was tested five times and four houses once. The results from two of the tests were unsatisfactory so the report is based on a total of 35 tests.

B. Key Results

It is clear from the tests that the results are much more variable in older, leakier houses, and it is not apparent that the range of variation is linked to factors such as wind speed or the inside/outside temperature difference.

The results also show that the quantities of moisture being moved through the houses is much greater than was estimated from earlier work. Quantities in excess of 300 Kg/day were calculated, and the average Total Moisture Source Strength (TMSS) from all the tests was 55 Kg/day. The average values for IMSS and VMSS were 15 and 40 Kg/day respectively.

Neither of the multi-tested houses in Halifax and Winnipeg were built to modern standards. The Winnipeg house is about 70 years old and the Halifax one must be more than 20 years old. The results of the different tests produced widely varying results. The air leakage rate for the Halifax house ranged from 90 L/s to 373 L/s and for the Winnipeg house from 43 to 205 L/s. In neither case is it apparent that those leakage rate variations could be accounted for by variations in ambient temperature, pressure, humidity or wind speed.

Even the multi-tested house in St. John's, which was completed in 1981 from a design modified to bring it to near R-2000 standards produced air leakage results which varied from 38 to 92 L/s.

The distribution of IMSS and TMSS per floor did not reveal any useful trends beyond the linear relationship between ACR vs IMSS and TMSS. However, analysis of the multi-tested house data on an individual basis did correlate well with the expected impact of wind and stack effect. There was no general correlation between IMSS and VMSS and wind effect or stack effect acting on the structure.

When the Team correlated the data with moisture problems in housing it was found that moisture troubled houses had the following characteristics.

1. IMSS is equal to or exceeds VMSS

2. The house is relatively air tight

3. The house design is such that the structure is incapable of processing moisture

The last two points are obvious. But one reason why moisture troubled houses have higher IMSS than VMSS values is because the IMSS values simply compound problems in the house caused by outside air introduced into the house.

C. Conclusions and Recommendations

While the data had wide variations and the only definitive relationship that could be established was that between ACR and IMSS or TMSS, some specific conclusions and recommendations can be made.

ACR, TMSS, VMSS and IMSS are useful indications of moisture problems in houses. While there were trends between the measurements and moisture problems, it must be emphasized that moisture problems are highly individualised. At this point one cannot assume that moisture troubled houses will have the IMSS value equal to or exceeding VMSS or set, for example, regional or local moisture indices based on the ACR vs IMSS/TMSS relationships.

Thus, the focus of future research should be on (a) refining and simplifying measurement procedures for ACR, IMSS and

TMSS and (b) using that information as part of a moisture diagnostic procedure of the type being developed by Scanada for EMR. Simplifying and refining procedures can be done using a variety of moisture measurement techniques simultaneously - the SF_6 test, use of an ambient air analyser such as a Miran 1-B and a door fan. While measurements with a door fan will be the least accurate, ultimately one may want to use a door fan as the tool for calculating IMSS and TMSS because it is the least expensive and most widely used by the contractor who would be rectifying existing moisture problems or avoiding future moisture problems when undertaking house retrofit work.

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1. INTRODUCTION

As houses have become more energy efficient, Eyre notes that "a low percentage (2.6%) of houses run the risk of moisture damage when energy conservation measures are applied."[1] In response to this real problem CMHC has conducted studies to determine relative humidity and potential condensation problems in housing. CMHC and NRC have been instrumental in developing a procedure for moisture source strength measurements in a house. The test protocol has been tested on houses in Ontario and BC, and CMHC now wishes to broaden its base of data collected by undertaking tests in other regions in the country. The results may be useful in understanding moisture behaviour in a house and in predicting the effectiveness of specific solutions that may be implemented in an effort to solve these problems.

The firms of Appin Associates, Winnipeg, Scanada Consultants Ltd., Ottawa, Eneraction Resources Inc., Regina, Pearson Glenbrook Associates, Halifax, and Provincial Consultants Ltd., St. John's, have come together to form a Team to undertake this assignment. Eneraction conducted all the house tests in Regina and travelled to the other three locations to co-ordinate the one-time testing of the four houses in each of the other cities. This action ensured that the testing protocol was accurately adhered to, and that the field testing personnel in each city was well versed in the testing procedure in order that

they may undertake the multiple testing of the one selected house.

1.1 Review of Previous Moisture Research

Despite the small amount of field data available, the moisture source strength information assembled to date shows interesting and useful results. The Team used this background review to provide some guidance on the research questions to be addressed in this assignment.

Eyre, cited previously, argues that research into moisture should focus on those houses which are marginally free of moisture problems but which can be shifted into a moisture problem condition when energy conservation measures are applied. He suggests that work should focus on those houses which are at risk due to high moisture stress (i.e. high internal moisture loadings) or are at risk by virtue of their moisture damage threshold (i.e. the level of accumulation in the building envelope).

BEST Corporation, in a study of BC and Ontario houses, made three recommendations relating to the improvement of the reliability of the moisture source strength test protocol.

The recommendations were as follows:

1. The test should be repeated two to three times per day in one house to provide an indication of the repeatability of the test procedure and of the expected variability of the results.

2. Moisture tests should be done on tight houses. The air change rate should be increased in increments (using a blower door) while conducting moisture source strength tests.

3. The sensitivity of the test procedure should be examined by introducing known amounts of moisture into a house by using a humidifier. BEST Corporation notes that such a test could be done using a dehumidistat controlling a humidifier.

White and Skvor in The House as a Moisture Source suggested that determination of the contribution of soil gas to house moisture levels is a key research question since the current data suggest that the apparent levels of house moisture are much higher than could be generated by the occupants themselves. This particular research question unfortunately could not be addressed in this work because there was no "pre" and "post" retrofit work was done to isolate the house living

space from the basement or crawl space.

White and Skvor also wished to identify the gases contained in soil gas (radon is a likely gas) and they wanted to explore the longer term average rates of moisture production. They also wanted to look at moisture source strength in houses without forced air systems and the impact of pressurizing the house on the moisture generation rate. Unfortunately this work could not be done as part of this project.

1.2 Report Organization

Chapter 1 is the introduction. Chapter 2 outlines the procedures followed in the project. Chapter 3 provides the results. Chapter 4 gives the Team's conclusions and recommendations.

Appendices 1,2, & 3 contain the detailed data, CMHC's recommended test procedures for moisture source strength testing and floor plans of the houses respectively.

2. PROCEDURES

Most of the test houses were selected because it was known that the occupants complained of problems which appeared to be moisture related. The review of previous work suggested that this was the most appropriate approach. Some of the newer houses tested were selected to see how they performed, and to compare the performance of the older houses against that of the new ones. Forced air heating systems were present in all the newer houses, whereas the older houses had hot water systems which allow air to be moved in the house by convection. Some of the houses had wood stoves which supplied supplementary heat. Appendix 1 contains the data collected by the Team. A description of each heating system is included in Table 1, the data summary.

The test procedure used by the Team followed CMHC's Recommended Test Procedures for Internal Moisture Strength (attached as Appendix 2). The only variation to the test was that the furnace flue was not blocked and the pressure differential between the centre of the upwind wall and 1 m above the basement floor was not measured.

Inlets and outlets such as exhaust grills or dryer vents were not blocked because the Team wanted to leave each house in as natural a condition as possible.

For each test outside doors and windows were closed and a measured amount of Sulfur Hexafluoride (SF_6) gas, was released. The quantity of SF_6 released was calculated to provide a concentration of approximately 100 ppb within the house.

After the gas was released steps were taken to see that it was widely dispersed throughout the house. In the houses with forced air systems the gas was released adjacent to the furnace fan inlet, and the furnace fan was operated to disperse the gas. Air had to be mixed in the radiator-heated houses with pieces of cardboard used as fans, together with portable fans located in the house.

When the gas had been adequately dispersed throughout the house, measured samples of air were taken at (usually) three locations. At each location air samples were taken at intervals of precisely fifteen minutes. When five or six samples had been taken at each location the samples, coded for time and location, were sent off for analysis of SF_6 concentration. Each test was completed within a period of two hours from the time of release of the gas.

Using the results of the SF_6 analyses, which showed reduction of gas concentration over time, an air leakage rate was calculated for each location. Next an assessment was made of the share of total house volume represented by each sampling

location, with the sum of the shares making up the total house volume. In effect, an air change rate on a per floor basis was calculated (or area by area for bungalows). With those assessments, leakage rates, in litres per second (L/s) were calculated, to provide a total value of the leakage rate for the whole house.

One house in each city was selected for multiple testing and in each of those a total of five tests were carried out, often over a period of several days. All of the tests were conducted in the late winter of 1985/86. From the data collected calculations were made of indoor and outdoor humidity ratios, and of internal and total moisture source strength. The data collected, and the calculated values, are set out in Appendix 1. The detailed floor plans of each house can be found in Appendix 3.

3. RESULTS:

3.1 Results for Total Moisture Source Strength (TMSS), Ventilation Moisture Source Strength (VMSS) and Internal Moisture Source Strength (IMSS)

Figures 1, 2 and 3 show the results for TMSS, VMSS and IMSS plotted against Air Change Rate (ACR) (in L/s). There is a linear relationship between ACR vs TMSS, VMSS and IMSS.

This relationship is consistent with the findings of the BEST Corporation report[1] done in 1984. The ACR vs TMSS and IMSS graphs prepared by BEST are reproduced as Figures 4 and 5 in this report.

Table 1 shows a summary version of the data which is given in detail in Appendix 1.

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1) BEST Corporation Field Trials of Test Procedures to Determine Internal Moisture Source Strength July 1984.

Table 1

SUMMARY OF RESULTS AS OF MAY 31/87

No. No. & Test	Heating System	Flue Sealed?	Air Ch Heat	Air Ch Main Flr	Air Ch 2nd Flr	Air Ch AV.Air Ch Rate	ACH Loc 1	ACH Loc 2	ACH Loc 3	INSS Loc 1	INSS Loc 2	INSS Loc 3	TNSS Loc 1	TNSS Loc 2	TNSS Loc 3	INSS (Kg/Day)	INSS % of TNSS	VNSS (Kg/Day)	VNSS % of TNSS	TNSS (Kg/Day)	TNSS/INSS Ratio	TNSS/VNSS Ratio	Air Leakg (L/s)
N.1.	F/A El	N	0.16	0.30		0.24	17.7	9	0	7	3	0	10	4	0	10	71%	4	29%	14	1.40	3.50	25.7
N.2.	F/A Gas	N	0.25	0.35		0.30	16.2	20.7	42.7	14	15	34	17	20	44	29	78%	8	22%	37	1.28	4.63	36.9
N.3.	F/A Gas	N	0.32	0.35	0.35	0.35	20.9	20.9	38.1	9	0	16	13	12	23	17	65%	9	35%	26	1.53	2.89	41.8
N.4.	F/A Gas	N		0.22		0.21	3.9	4.6	7.2	2	2	2	3	4	3	6	55%	5	45%	11	1.83	2.20	11.6
N.5.1.	F/A Gas	N	2.91	1.76	0.99	1.94	29.4	70.9	100.3	10	25	39	14	36	55	76	71%	31	29%	107	1.41	3.45	206.6
N.5.2.	F/A Gas	N	2.43	1.19	0.81	1.51	24.1	47.9	87.1	6	9	14	10	21	37	30	43%	40	57%	70	2.33	1.75	159.1
N.5.3.	F/A Gas	N	1.05	1.03	0.52	1.16	15.3	41.2	66.3	1	4	2	6	16	22	9	20%	36	80%	45	5.00	1.25	122.8
N.5.4.	F/A Gas	N	0.90	0.70	0.36	0.70	10.6	28	35.1	0.5	1	1	5	14	17	3	8%	34	92%	37	12.33	1.09	73.7
N.5.5.	F/A Gas	N	1.00	0.12	0.09	0.41	2.7	6.8	35.8	-0.6	-1	-7	1	2	14	-7	-39%	25	139%	18	-2.57	0.72	43.3
N.1.	El Bbd	n.a.	0.00	0.15		0.12	5.2	6.8	5.2	1	1	1	3	3	3	4	60%	6	60%	10	2.50	1.67	15.1
N.2.	El Bbd,WS	n.a.	0.05	0.12		0.06	5.3	0	4.1	2	0	2	4	0	4	4	44%	5	56%	9	2.25	1.80	9.6
N.3.1.	El Bbd,WS	n.a.	0.30	0.34		0.30	14	11.1	22.8	5	5	5	9	8	12	16	53%	14	47%	30	1.88	2.14	47.9
N.3.2.	El Bbd,WS	n.a.	0.17	0.25		0.24	10.3	14.4	12.9	1	1	-1	7	9	7	1	4%	22	96%	23	23.00	1.05	37.6
N.3.3.	El Bbd,WS	n.a.	0.35	0.43		0.41	17.7	28.6	26.6	9	10	9	12	14	14	28	68%	13	32%	41	1.46	3.15	64.9
N.3.4.	El Bbd,WS	n.a.	0.63	0.63		0.58	25.5	18.1	48	9	7	29	12	8	34	41	88%	10	20%	51	1.24	5.10	91.5
N.4.	El Bbd	n.a.	0.17	0.17		0.24	5.5	5.5	10.4	0.2	0	0.4	5	5	17	1	4%	27	96%	28	28.00	1.04	29.4
N.5.	F/A El	n.a.				0.88	34.7	35.8	55.7	13	12	10	27	26	48	44	47%	50	53%	94	2.14	1.88	126.1
R.1.	El Bbd	n.a.	0.66	0.70		0.92	19.3	18.2	63.3	11	5	34	19	12	59	45	52%	41	48%	86	1.91	2.10	100.8
R.2.	El Bbd	n.a.	0.37	0.29		0.37	7.2	10.9	18.4	4	6	10	6	10	16	21	66%	11	34%	32	1.52	2.91	36.4
R.5.	El Bbd	n.a.	0.13	0.43		0.30	12.1	14.3	7.3	1	0.3	-0.3	9	9	4	1	5%	21	95%	22	22.00	1.05	33.7
R.6.	El Bbd	n.a.	0.22	0.23		0.22	6.2	5.4	11.9	2	2	4	5	5	10	8	40%	12	60%	20	2.50	1.67	23.7
R.7.1.	F/A El	n.a.	0.35	0.48	0.55	0.46	38.3	33.5	22.9	-1	-3	-2	28	22	15	-1	-2%	66	102%	65	-65.00	0.98	94.4
R.7.2.	F/A El	n.a.	0.56	0.48	1.25	0.77	87.2	33.5	36.7	3	1	3	66	25	30	-17	-12%	140	114%	123	-7.24	0.88	157.3
R.7.3.	F/A El	n.a.	0.31	0.43	0.57	0.44	39.7	30	28.3	17	7	8	33	20	17	10	14%	60	86%	70	7.00	1.17	90.0
R.7.4.	F/A El	n.a.	0.36	0.64	1.44	0.75	100.4	38.7	23.6	59	15	12	101	27	22	-4	-3%	149	103%	145	-36.25	0.97	154.7
R.7.5.	F/A El	n.a.	0.10	1.03	3.42	1.02	238.5	127.6	6.6	86	26	2	214	95	5	-50	-16%	350	116%	300	-6.16	0.86	372.6
R.1.	F/A Gas	N	1.53	1.53		1.53										66	43%	88	57%	154	2.33	1.75	240.6
R.2.	F/A Gas	N	0.21	0.27		0.26	17.1	13.3	22.8	11	10	15	19	15	26	21	62%	13	38%	34	1.62	2.62	30.6
R.3.	F/A Gas	N	0.25	0.26		0.29	11.7	12.5	36.3	4	2	11	9	8	28	10	38%	16	62%	26	2.60	1.63	36.3
R.4.	F/A Gas,N	N	0.17	0.18		0.18	12.6	11.9	10.2	4	2	5	9	7	12	7	41%	10	59%	17	2.43	1.70	24.5
R.5.1.	F/A El	n.a.	0.16	0.22	0.19	0.19	13.3	7.3	9.7	2	2	2	9	6	7	7	30%	16	70%	23	3.29	1.44	30.3
R.5.2.	F/A El	n.a.	0.29	0.34	0.34	0.32	28.6	13	17	11	7	10	18	11	16	27	61%	17	39%	44	1.63	2.59	51.2
R.5.3.	F/A El	n.a.	0.42	0.42	0.37	0.41	35.4	14.2	25.4	10	4	11	19	9	19	23	50%	23	50%	46	2.00	2.00	65.1
R.5.4.	F/A El	n.a.	0.20	0.33	0.34	0.31	20	13	17	8	5	6	13	8	11	19	61%	12	39%	31	1.63	2.58	50.0
R.5.5.	F/A El	n.a.	0.19	0.20	0.26	0.24	17	10	11.5	5	3	3	11	7	7	12	48%	13	52%	25	2.08	1.92	30.6
AVERAGE			0.55	0.51	0.74	0.55	27.01	22.25	28.56	9.54	5.77	8.77	21.94	14.65	19.12	15		40		55	3.72	1.37	79.2

F/A = Forced Air
El = Electric
WS = Wood Stove
Bbd = Baseboard Heat

INSS/TNSS %	VNSS/TNSS %
26.9%	73.1%

AR_i	AR_o	Tin °C	Tout °C	Tin-Tout °C	Wind (Km/hr)	Wind Direction	RHo %	Age Years	Age & Test	No. No.
0.0053	0.0016	19.0	-0.4	27.4	11.0		76	34	W.1.	
0.0099	0.0023	22.0	-2.0	24.0	20.0		69	38	W.2.	
0.0058	0.0018	19.0	-5.0	24.0	12.5		70	70	W.3.	
0.0080	0.0030	18.0	7.0	11.0	16.0		61	25	W.4.	
0.005	0.0014	16.2	-9.0	25.2	5.0		73	70	W.5.1.	
0.0042	0.0024	18.5	-2.0	20.5	24.0		73	70	W.5.2.	
0.0035	0.0020	17.1	-2.0	19.1	13.0		86	70	W.5.3.	
0.0040	0.0046	19.0	9.0	10.0	19.0		61	70	W.5.4.	
0.0039	0.0055	15.8	9.0	6.8	11.0		76	70	W.5.5.	
0.0063	0.0039	19.2	6.0	13.2	35.0	[illegible]	66		B.1.	
0.0092	0.005	19.5	4.0	15.5	25.0	[illegible]	95		B.2.	
0.006	0.0028	14.2	2.0	12.2	25.0	[illegible]	63	6	B.3.1.	
0.0059	0.0057	14.9	7.0	7.9	22.5	[illegible]	89	6	B.3.2.	
0.0061	0.0010	16.0	-2.0	18.0	40.0	[illegible]	57	6	B.3.3.	
0.0053	0.001	16.7	-10.0	26.7	80.0	[illegible]	56	6	B.3.4.	
0.0091	0.0089	22.5	14.5	8.0	24.0	[illegible]	85	50	B.4.	
0.0072	0.0039	20.7	2.0	18.7	7.5	[illegible]	87	50	B.5.	
0.0087	0.0041	21.9	1.7	20.2	17.5	[illegible]	91	5	B.1.	
0.0080	0.0032	22.5	-2.0	25.3	10.0	[illegible]	100	5	B.2.	
0.0063	0.0061	17.8	6.1	11.7	2.5	[illegible]	100	3	B.5.	
0.0084	0.005	16.5	3.3	13.2	0.0		100	3	B.6.	
0.0066	0.0066	13.1	10.6	2.5	20.0	[illegible]	82		B.7.1.	
0.0076	0.0085	14.5	13.9	0.6	20.0	[illegible]	84		B.7.2.	
0.0073	0.0062	15.0	12.8	2.2	4.0	[illegible]	67		B.7.3.	
0.009	0.0093	18.2	18.3	-0.1	0.0		70		B.7.4.	
0.0079	0.0091	18.1	17.2	0.9	4.0	[illegible]	74		B.7.5.	
0.0067	0.0038	20.0	-1.0	21.0	21.0	[illegible]	100	23	B.1.	
0.0119	0.0047	22.5	4.0	18.5	8.0	[illegible]	85	15	B.2.	
0.0076	0.0049	20.9	6.1	14.8	17.0	[illegible]	76	1	B.3.	
0.0071	0.0042	19.5	3.0	16.5	12.5	[illegible]	82	1	B.4.	
0.0075	0.0053	20.6	4.4	16.2	4.0	[illegible]	100	5	B.5.1.	
0.0092	0.0036	21.8	-2.0	23.8	11.0	[illegible]	100	5	B.5.2.	
0.0073	0.0036	21.7	-2.0	23.7	21.0	[illegible]	100	5	B.5.3.	
0.0066	0.0027	18.7	-6.0	24.7	50.0	[illegible]	100	5	B.5.4.	
0.0068	0.0035	20.2	-2.0	22.2	21.0	[illegible]	100	5	B.5.5.	
0.0071	0.0044	18.6	3.0	15.6	18.1		82	26		

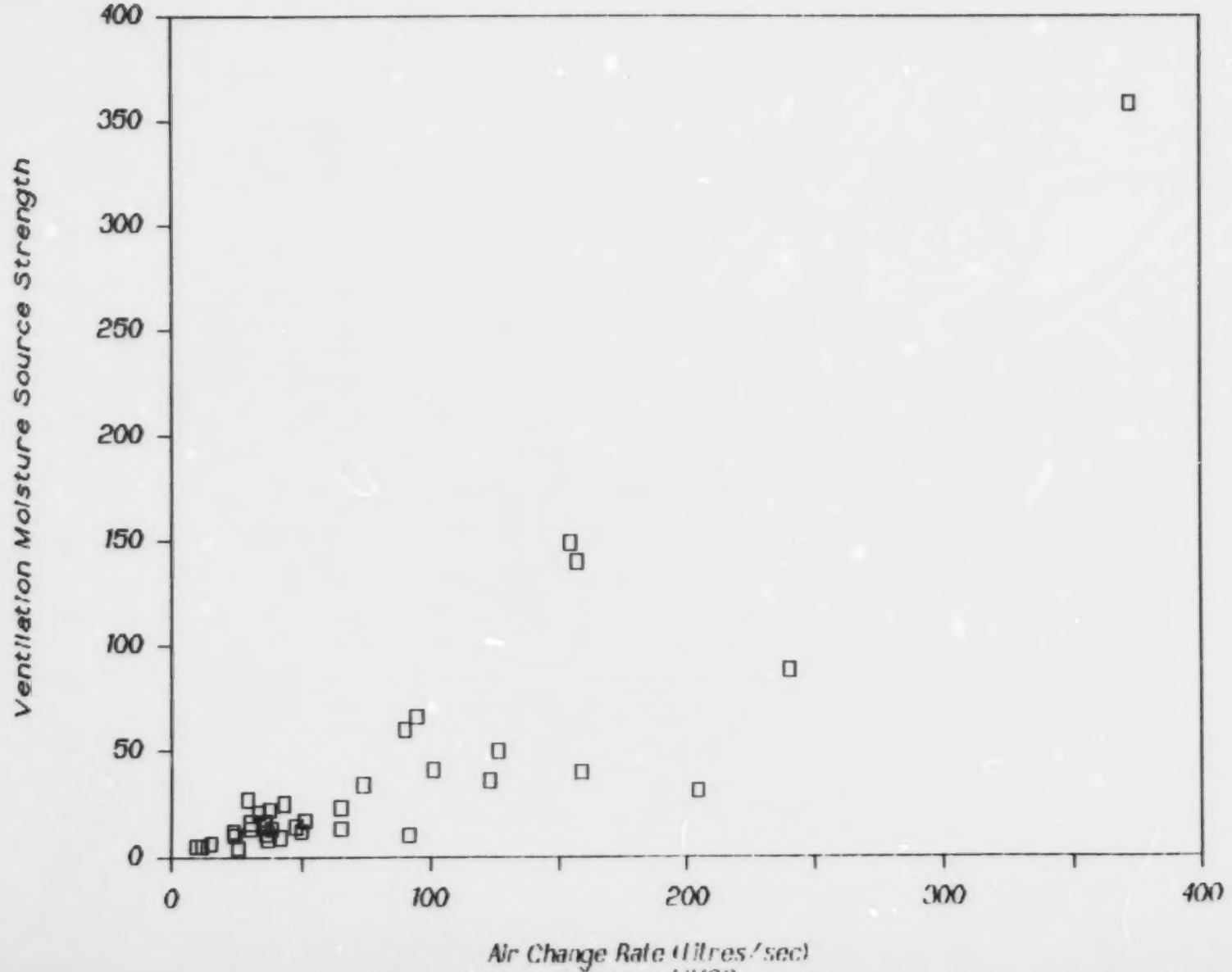

Air Leakage Rate vs VMSS
Ventilation Moisture Source Strength
400
350
300
250
200
150
100
50
0
0
100
200
300
400
Air Change Rate (litres/sec)

Figure 1

Air Leakage Rate vs IMSS

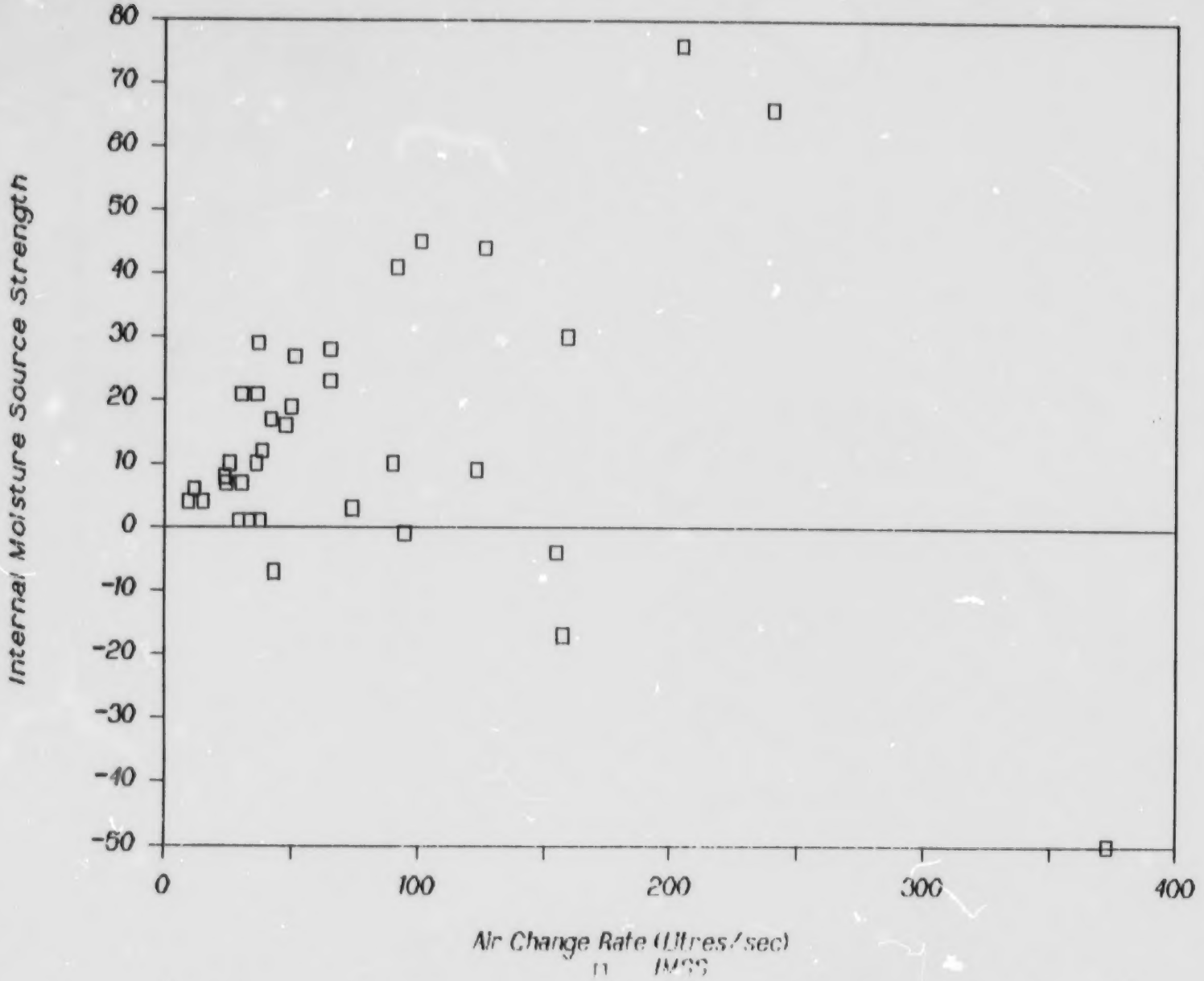


Figure 2

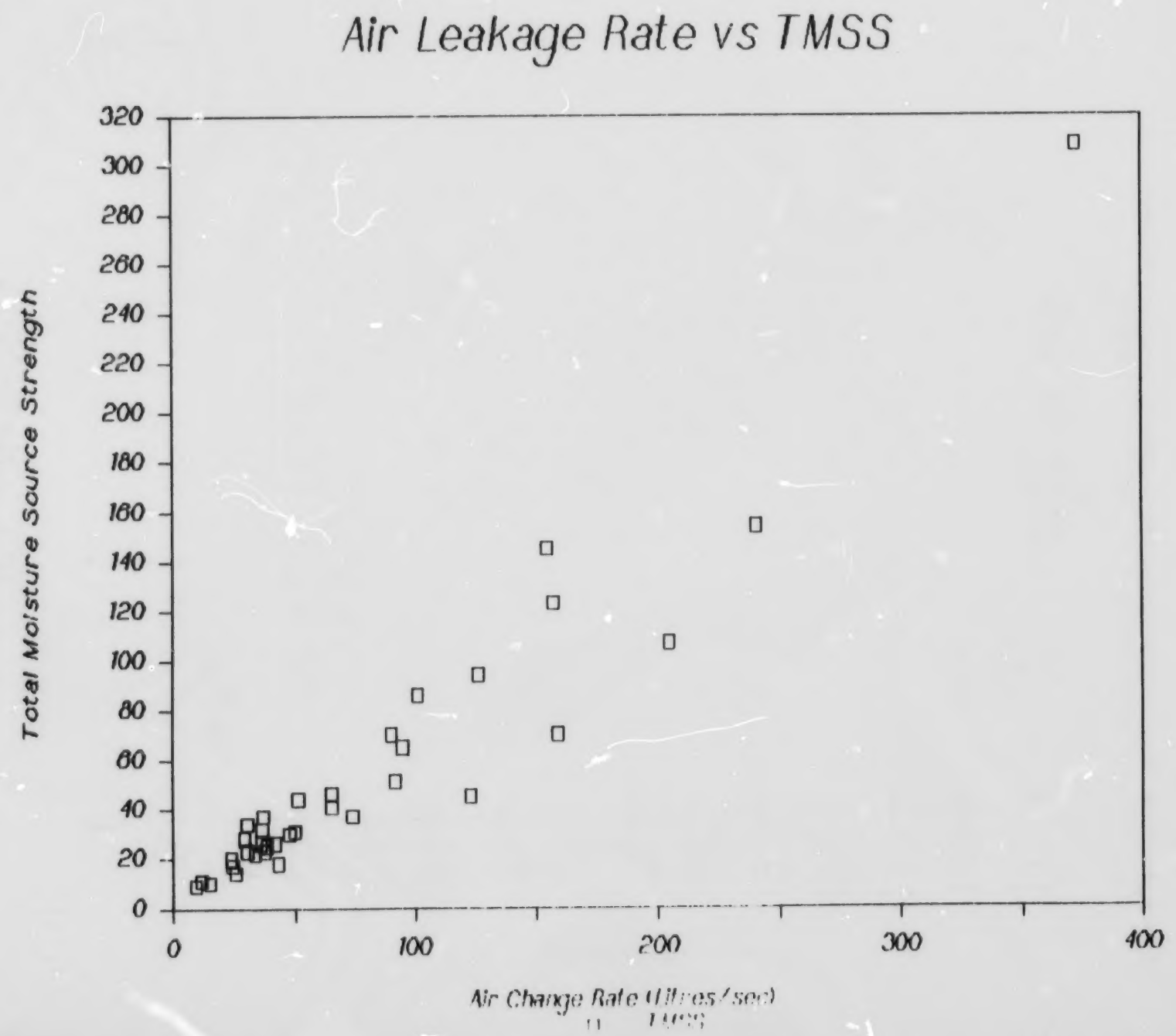

Air Leakage Rate vs TMSS
Total Moisture Source Strength
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
0
100
200
300
400
Air Change Rate (Litres/sec)

Figure 3

Figure 4 (from "Field Trials of Test Procedures to Determine Internal Moisture Source Strength" by BEST Corporation)

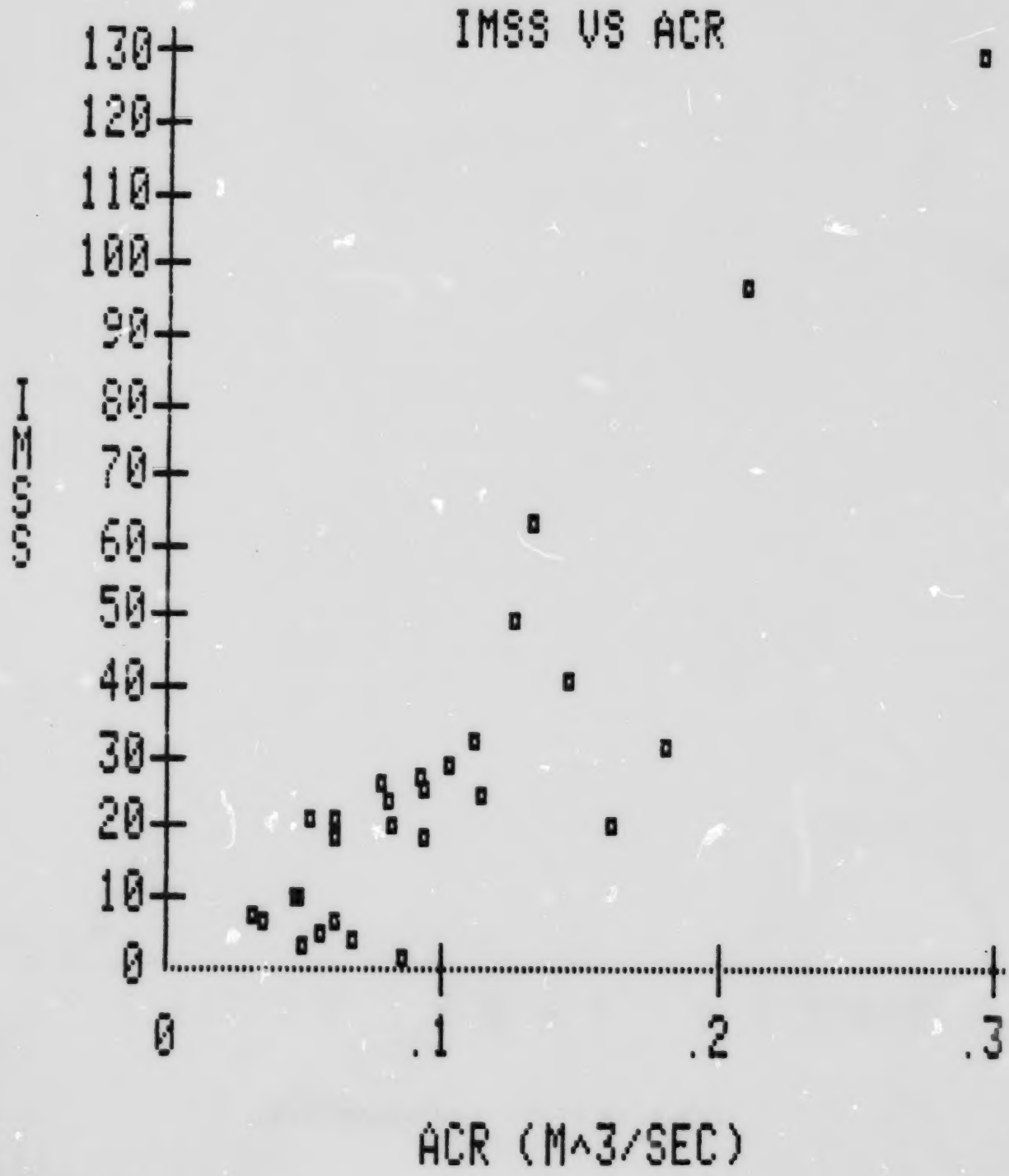
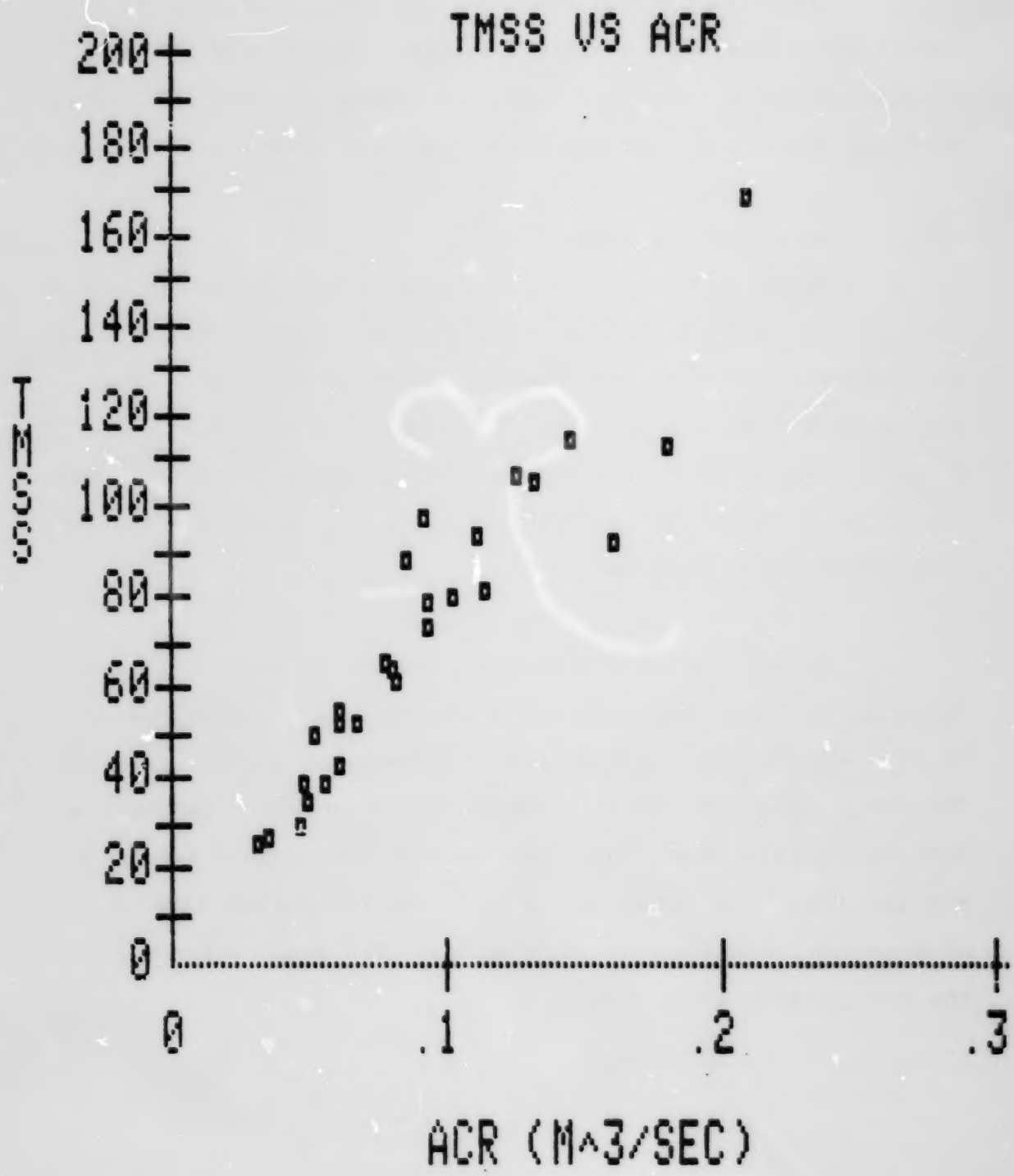


Figure 5 (from "Field Trials of Test Procedures to Determine Internal Moisture Source Strength" by BEST Corporation)



3.2 House by House Analysis

The Team found that it was very difficult to draw trends based upon such a limited sample. Analysis of the data on a house by house basis did show some trends between air leakage moisture source strength and the presence of moisture problems.

3.2.1 Newfoundland Houses

House N.1 is a bi-level house which faces the sea on the east and south exposures. The homeowner complained of mould and mildew. The test was done on March 19 at 3 pm. The air change rate was .12 AC/h or 15 L/s and the TMSS was only 10 Kg/day. The Relative Humidity in the basement (RHib) was 44%. These results show that a tight coastal house, even with low TMSS can have moisture problems.

House N.2 is a bungalow with an unfinished basement. The house had moisture problems in the bathroom, bad mildew/mould on the window sills and serious window condensation problems. The inside Relative Humidity (RHib) was about 85%. The test was done on February 26 at 2 pm. The outside temperature 4°C and the RHo was 95%. The house had a very low air change rate of .06 AC/h or 5.3 L/s and a TMSS of 9 Kg/day. The results for N.2 show the same pattern as in N.1.

House N.3 was the multi-tested house (tested 4 times). This a low energy house and a door fan test indicated that it built close to R-2000 standards. The house is clearly designed to process moisture with no adverse effects. A wood stove was present. Despite a basement RH of 77%, the homeowner reported no moisture problems. The air change rates ranged from .24-.58 AC/h or 38-92 L/s. TMSS values were 30, 23, 41, and 51 Kg/day for tests H.3.1 to H.3.4 respectively. The four tests were done from March 19 - 25 during the morning, afternoon and evening. Winds were always above 40 km/h. The data below show the high RHib that the house was subjected to.

	Tout	RHo	RHib	TMSS
N.3.1	1	57	77	30.22
N.3.2	7	89	60	23.33
N.3.3	-2.8	57	56	40.86
N.3.4	-10	56	72	51.87

During the 3rd test there was a slight negative IMSS value (-1.00 Kg/day). A negative value means that the house is absorbing rather than releasing moisture. It happens to coincide with the lowest basement RH value.

House N.4 was a bi-level which experienced moisture problems on the leaside of the structure. The house was .24 AC/h or 29 L/s. The house is electrically heated. The TMSS measured on April 26 was 18 Kg/day.

House N.5 was a bungalow with a finished basement. The test was done on April 29 when the outside RH was 89%. The owner reported no moisture problems. The air change rate was .8 AC/h or 126 L/s indicating a very leaky house. The TMSS value was 94 Kg/day suggesting that this leaky house can process more moisture than other Newfoundland houses in this study with no problem.

3.2.2 Halifax Houses

House H.1 was a bungalow with a wood stove. The test was done on February 27 around noon. Despite a relatively high air change rate of .9 AC/h or 100 L/s had mould and moisture problems. The TMSS was 86 Kg/day.

House H.2 was a bungalow with a part slab/part exposed bedrock basement. Despite the house construction, the TMSS was only 32 Kg/day. The owner reported no moisture problems. The test was conducted on February 28 in the morning. The basement RH was 49%.

House H.3 was a bi-level with a wood stove. The test was conducted on March 4 at noon when the outside RH was 94%. The test samples did not arrive intact at the lab and the results could not be used.

House H.4 was an owner built house. The homeowner reported having moisture problems only when the family first

moved into the home. The house has a central exhaust system. Unfortunately the front door was left open during the test and the data could not be used.

House H.5 was a bi-level. The test was conducted on March 4 in the late afternoon. The outside RH was 100%. The house air change rate was .3 AC/h or 34 L/s and the homeowner reported no moisture problems. The TMSS was 22 Kg/day.

House H.6 was a bi-level. The test was conducted on March 4 in the evening when the outside RH was 100%. The basement RH was 69%. The air change rate was .22 AC/h or 24 L/s. The house had moisture problems which were likely compounded by the presence of a 150 gallon fish tank which is open to the house.

House H.7 deserves special mention. The data from five tests resulted in extremely high TMSS values of 100 - 307 Kg/day. Air change rates varied from .46 to 1.82 AC/h or 90 to 373 L/s. The house also had large negative TMSS values of -1 to -50 Kg/day suggesting that the house is absorbing rather than releasing moisture. This phenomena of the house absorbing moisture normally happens in the summer. The basement in this house is unfinished and a sump pump is installed. It was noted that during the first test the pump chamber was full of water, but it was empty during Test No. 3. The occupants had expressed some

concern about gas entry into the house.

During the tests, outside temperatures were between 10°C and 18°C and wind speeds were from 0 km/hr to 20 km/hr. There is no obvious relationship between Average Air Change Rate and Outdoor Humidity Ratio, or between Average Air Change Rate and either outdoor temperature or wind speed. Moreover, in this house the air change rate is lowest in the basement and highest on the second floor. The range of Average Air Change Rates, over the five tests was 4:1 and there does appear to be a direct positive correlation between Air Change Rate and Total Moisture Source Strength (and between Average Air Change Rate and Internal Moisture Source Strength or IMSS).

While the Team has no firm explanation for these results, a number of observations can be made.

1. The person responsible for conducting the test (who is also the owner) reported that the house has suffered and continues to suffer from severe moisture problems. There were pools of water in the exposed basement floor during the test. The floor was in the process of being broken up in order to replace the drainage system so there was exposed soil in places. The house basement is

also built on a layer of clay which would tend to trap moisture from internal and infiltration sources. The house has severe mold and attic condensation problems. The heating system had been converted from oil to electric heat one month prior to the test. This conversion would tend to increase moisture buildup.

2. The person conducting the test indicated that the weather on that day ranged from rain to overcast to sunny skies. Wind speed and direction varied as well. Combined with the errors in using a sling psychrometer, the variable climate made it difficult to take accurate relative humidity measurements outdoors. The data below shows that the relative humidity as measured at the house and as recorded at Shearwater Naval Base 5 km away varied dramatically.

TEST #	HOUSE RHo	SHEARWATER RHo
H.7.1	84%	88%
H.7.2	84%	69%
H.7.3	75%	44%
H.7.4	70%	30%
H.7.5	64%	42%

If one substitutes in the Shearwater RHO value for the measured value, the IMSS and TMSS values are as follows:

			Using Measured RHo		Using Shearwater RHo	
TEST #	LOCATION #		IMSS	TMSS	IMSS	TMSS
H.7.1	1	S.Bd.N[1]	1.35	28.16	-0.64	28.16
	2	M.H.C	-1.31	21.98	-3.03	21.98
	3	B.U.S	-0.68	15.50	-1.88	15.50
Whole House			-0.77	65.35	-5.66	65.35
H.7.2	1	S.BD.N	-11.22	66.12	2.74	66.12
	2	M.H.C	-4.48	25.16	0.87	25.16
	3	B.U.S	-3.04	29.76	2.88	29.76
Whole House			-17.22	123.25	8.14	123.25
H.7.3	1	S.Bd.N	7.56	33.42	16.50	33.42
	2	M.H.C	0.00	19.86	6.86	19.86
	3	B.U.S	3.24	16.57	7.85	16.57
Whole House			10.27	69.55	30.75	69.55
H.7.4	1	S.Bd.N	3.77	100.61	59.46	100.61
	2	M.H.C	-2.41	27.23	14.63	27.23
	3	B.U.C	-1.18	21.79	12.03	21.79
Whole House			-3.74	145.26	81.94	145.26
H.7.5	1	S.Bd.N	-13.48	214.13	85.76	214.13
	2	M.H.C	-26.89	95.19	26.34	95.19
	3	B.U.C	-0.82	5.45	1.91	5.45
Whole House			-49.72	307.55	106.06	307.55

[1] See Appendix 1 for an explanation of the location codes.

One can see that the IMSS values are no longer negative when the Shearwater RHo values are used. These differences will likely be less pronounced when the test is done in more stable inland climates. The experience does suggest a stricter protocol for taking relative humidity measurements when conducting the test in coastal climates or under extreme variations in the climate.

3. It is interesting to note that for H.7, the SF_6 concentrations varied from 1.4 to 650 ppb. When

the concentrations are compared to wind conditions, they seem to follow expected wind and sack action conditions in the house. When there was a North wind of 20 km/hr, wind action predominated and the SF_6 decay values were the same as in other houses. Where there were calm conditions stack action predominated and the concentrations of 300 - 650 ppb were measured on the second floor of the house. The point of measurement was at an up wind location.

4. Finally test H.7.5 resulted in the highest TMSS value of 308 Kg/day. While other H.7 tests resulted in similarly high values of 65, 123, 69 and 145 for tests H.7.1 to H.7.4 respectively, there were 2 less samples taken in each of the 3 locations for H.7.5. This suggests that H.7.5 is likely less accurate than the other tests.

3.2.3 Regina Houses

House R.1 was a bungalow with a wood stove and a forced air heating system. The test was done on March 11 in the morning. The air change rate was 1.53 AC/h or 240 L/s. There were no moisture problems reported even though the TMSS was 154 Kg/day. Clearly the large air change rate allows the house to process the large amounts of moisture present.

House R.2 was a bungalow with a crawlspace. The test was done on March 14 in the morning when the outside RH was 86% at 5°C. The house air change rate is .24 AC/h or 30 L/s. The house had window condensation problems. There are vents cut into the basement floor which allow crawl space air into the house. The TMSS value was 34 Kg/day. The presence of the crawlspace vents likely contributes to the problem.

House R.3 was a two storey house with a fireplace and HRV. The test was conducted on March 15 at noon when the outside RH was 76% at 6°C. The house air change rate was .29 AC/h or 36 L/s. The house had no moisture problems. The TMSS was 28 Kg/day with the HRV turned off during the test.

House R.4 is a bungalow with a wood stove and HRV. THe air change rate is .18 AC/h or 25 L/s. The test was done April 23 in the morning when the outside RH was 70% at 4°C. The homeowner noticed condensation problems when the HRV is turned off. The TMSS value was 17 Kg/day with the HRV turned of during the test.

House R.5, in Regina was tested five times during March 8 - 26. This is a super-insulated house with electric forced air heat. It was built in 1981, and has a poured concrete basement. A heat exchanger is installed but it was switched off some time before the tests began and did not operate during them. The

outside RH ranged from 60 - 100% and the outside temperature ranged from -6°C to +10°C. During the tests, wind speeds from 4 to 50 km/hr with the highest wind speed occurring when the temperature was -6°C.

Air change rates ranged from .19 to .41 AC/h or 35 - 65 L/s. The TMSS values ranged from 6 - 23 Kg/day. No moisture problems were reported. Moreover, the air change rates calculated at different levels in the house show little variation from floor to floor and there was no consistency as to which floor indicates the highest level.

Although one might expect to obtain better data from the tests on a relatively new house built to modern standards, and that the data is good is to some extent confirmed by the narrow range into which the calculated values of Average Air Change Rate fall - no correlation is apparent between Average Air Change Rate and any of the other parameters - not even with IMSS or TMSS, both of which are a function of Air Change Rate.

3.2.4 Winnipeg Houses.

House W.1 was a bungalow with a finished basement. The test was done on March 20 in the morning when the outside RH was 76% at -8°C. The air change rate was .24 AC/h or 26 L/s. The moisture problems were reported and the TMSS was 14 Kg/day.

House W.2 was a bungalow. The test was done on March 20 in the afternoon when the outside RH was 69 at -2°C. The air change rate was .3 AC/h or 37 L/s. There was evidence of moisture damage on the window sills. The TMSS was 37 Kg/day.

House W.3 was a 2 storey house with a one storey addition. The air change rate was .35 AC/h or 42 L/s. The TMSS was 25 Kg/day.

House W.4 was a bungalow constructed with a slab on grade with ducts cast into the slab. The air leakage rate was .21 AC/h or 12 L/s. The outside RH was 65% at 6°C. The house indoor RH was 68% - high for prairie houses tested. The homeowner complained of serious moisture and mold problems and excessive window condensation. The carpet affixed to the slab was lifting in places indicating moisture diffusion through the slab.

Despite these problems the TMSS value was only 11 Kg/day.

House W.5 was a 2-storey house, over 60 years old. Heating is by hot-water radiators, with a gas-fired boiler. The 5 tests were done at different times of the day between April 12 - 17. The air change rate varied from .41 to 1.94 AC/h or 43-204 L/s.

Outside temperatures during the tests ranged from -9°C to +9°C, and outside absolute humidities from .0014 to .0055 kg/kg dry air. Wind speeds ranged from 5 to 24 km/hr.

There were problems with uneven heating and severe winter condensation on some windows. The test results reflect the difficulties that were experienced in getting uniform mixing of the tracer gas.

TMSS values were 107, 70, 45, 37, 18 Kg/day for tests W.5.1 - 5.5. There was a slight negative IMSS for test W.5.5 indicating the basement was absorbing moisture.

While there was a strong negative correlation in this case between the Outdoor Humidity Ratio and the Air Change Rate. There was, however, no obvious relationship between Indoor Humidity Ratio and Air Change Rate and any of the other parameters.

The data below show the Air Change Rates as calculated in the different locations in the house. The rates can be seen to increase markedly at lower levels to about three times the rate, in the basement, as on the second floor because the flue was not sealed during the tests.

Test	Location	ACR (L/s)
W.5.1	Bsmt	104.3
	Main Flr	70.9
	Second Flr	29.4
	Whole House	204.6
W.5.2	Bsmt	87.1
	Main Flr	47.9
	Second Flr	24.1
	Whole House	159.1
W.5.3	Bsmt	66.3
	Main Flr	41.2
	Second Flr	15.3
	Whole House	122.8
W.5.4	Bsmt	35.1
	Main Flr	28.0
	Second Flr	10.6
	Whole House	73.7
W.5.5	Bsmt	35.8
	Main Flr	4.8
	Second Flr	2.7
	Whole House	43.3

3.2.5 Trends Emerging from the Data

The data showed that moisture problems existed in houses which ranged from being very leaky to being relatively tight. Many of these tight houses with moisture problems had relatively low TMSS and IMSS values. The leaky houses with moisture problems had correspondingly high TMSS and IMSS values. Thus while a leaky house may be capable of processing more moisture than a tight house, such houses are still susceptible to moisture problems. These general findings are shown in Table 2.

Table 2

CORRELATION OF MOISTURE PROBLEMS WITH ACR, IMSS, TMSS, VMSS

Moisture Problem		ACR	IMSS	VMSS	TMSS
N.1	Mildew and dry rot	15.1	4	6	10
N.2	Mildew and mould on window sills - bad condensation	9.4	4	5	9
N.3	No problems identified	37.6-91.5	1-41	10-22	23-51
N.4	Moisture problems - mould and mildew - leaky	29.4	1	27	28
N.5	No problems identified	126.1	44	50	94
R.1	No problems identified	240.6	66	88	154
R.2	Condensation on some windows	30.4	21	13	34
R.3	No problems identified	36.3	10	16	26
R.4	Condensation on cold days	24.5	7	10	17
R.5	No problems identified	30.3-65.1	7-27	12-23	23-46
W.1	Some moisture damage in walls under windows	25.7	10	4	14
W.2	No problems identified	36.9	29	8	37
W.3	No problems identified	41.8	17	9	26
W.4	Very high humidity, excessive window condensation - mould and mildew	11.6	6	5	11
W.5	Water entry through foundation - efflorescence and mortar deterioration	43.3-204.6	76	25-90	18-107
H.1	Mould smell, condensation	100.8	45	41	86
H.2	Mould on windows, moisture in basement	36.4	21	11	32
H.3	No problems identified	N/A	1	21	22
H.4	No problems but door left open	N/A	N/A	N/A	N/A
H.5	No problems identified	33.7	N/A	N/A	N/A
H.6	Moisture - fish tank	23.7	8	12	20
H.7	Sump pump in basement, severe moisture probs	90-372.6	-50 to -1	60-358	65-308

The data further suggests that houses with moisture problems generally have IMSS values which are equal to or exceed relative to VMSS. IMSS in effect compounds the problems that houses, especially those on the East Coast, face from outside moist air which enters the structure.

Care must be taken that this trend will always be the case. There were houses like N.3 which had high IMSS relative to VMSS but which had no moisture problems. This is because this particular house was designed to be close to R-2000 standards and is capable of processing large quantities of moisture. Houses which are extremely leaky may be capable of processing large quantities of moisture regardless of whether the moisture is from infiltration or internal sources.

Figures 6 to 9 show the split between IMSS and VMSS for each of the 35 tests. Readers can compare the figures to Table 2 to see the trend.

IMSS and VMSS for St. John's Tests

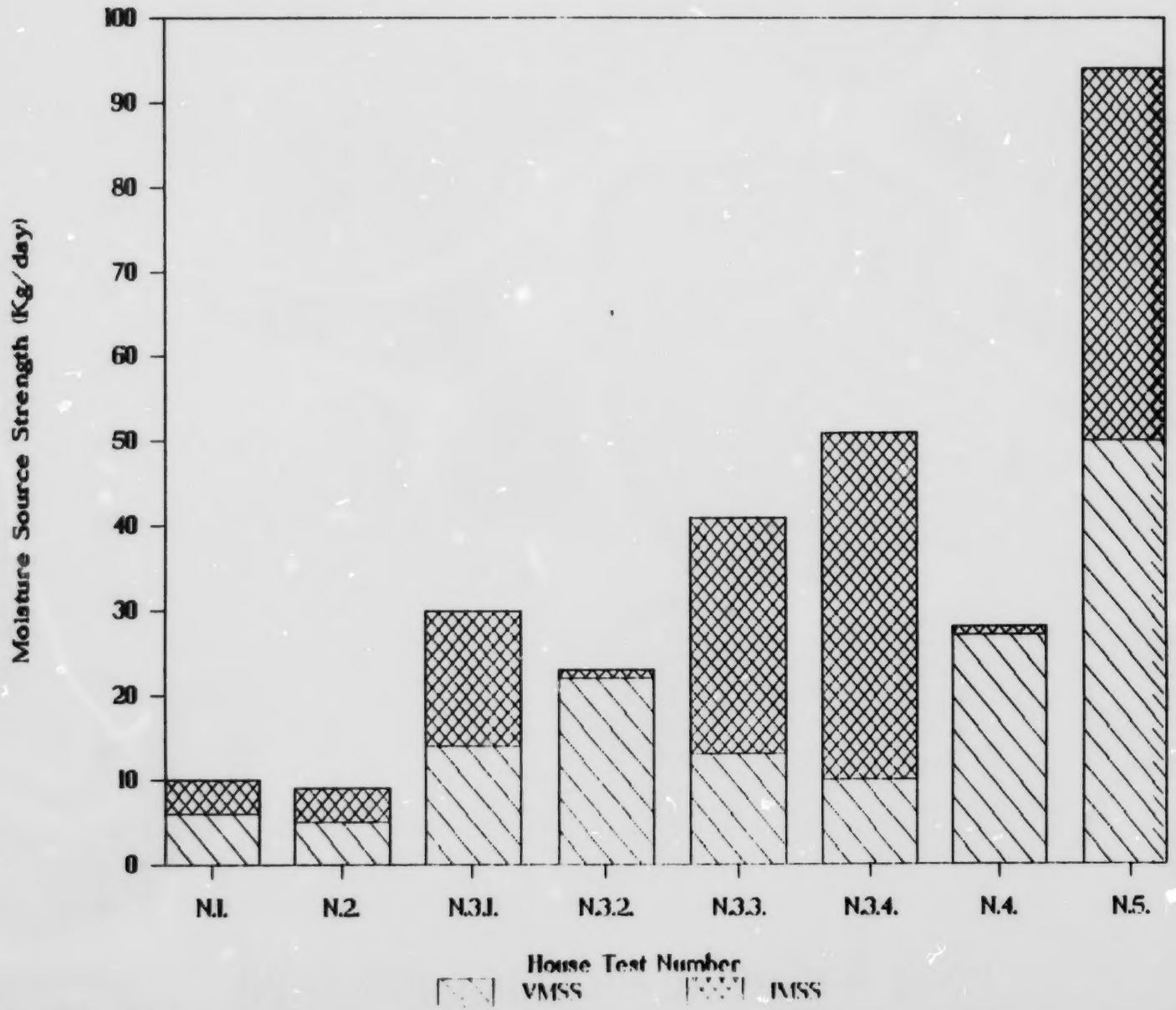


Figure 6

IMSS and VMSS for Winnipeg Tests

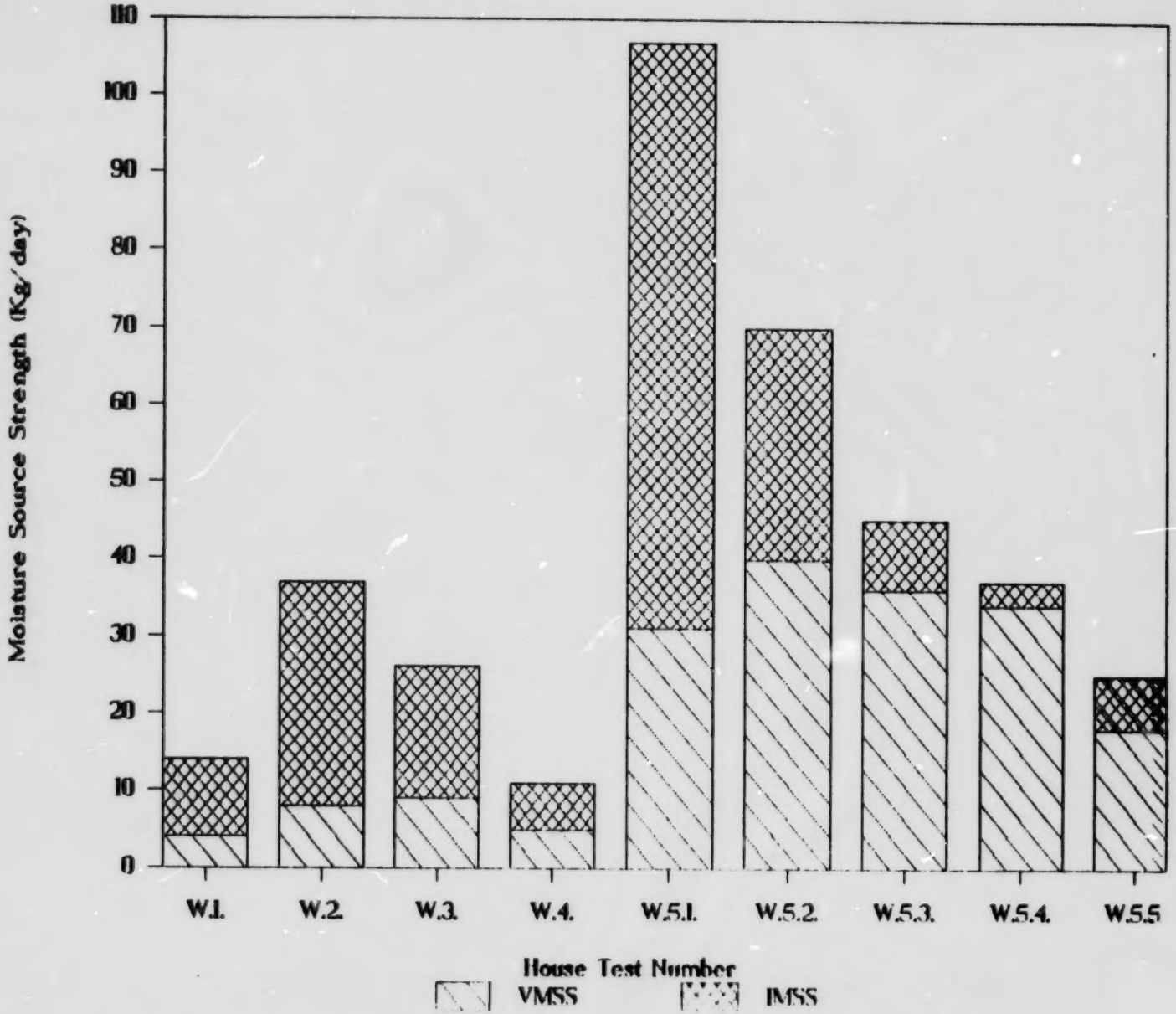


Figure 7

IMSS and VMSS for Regina Tests

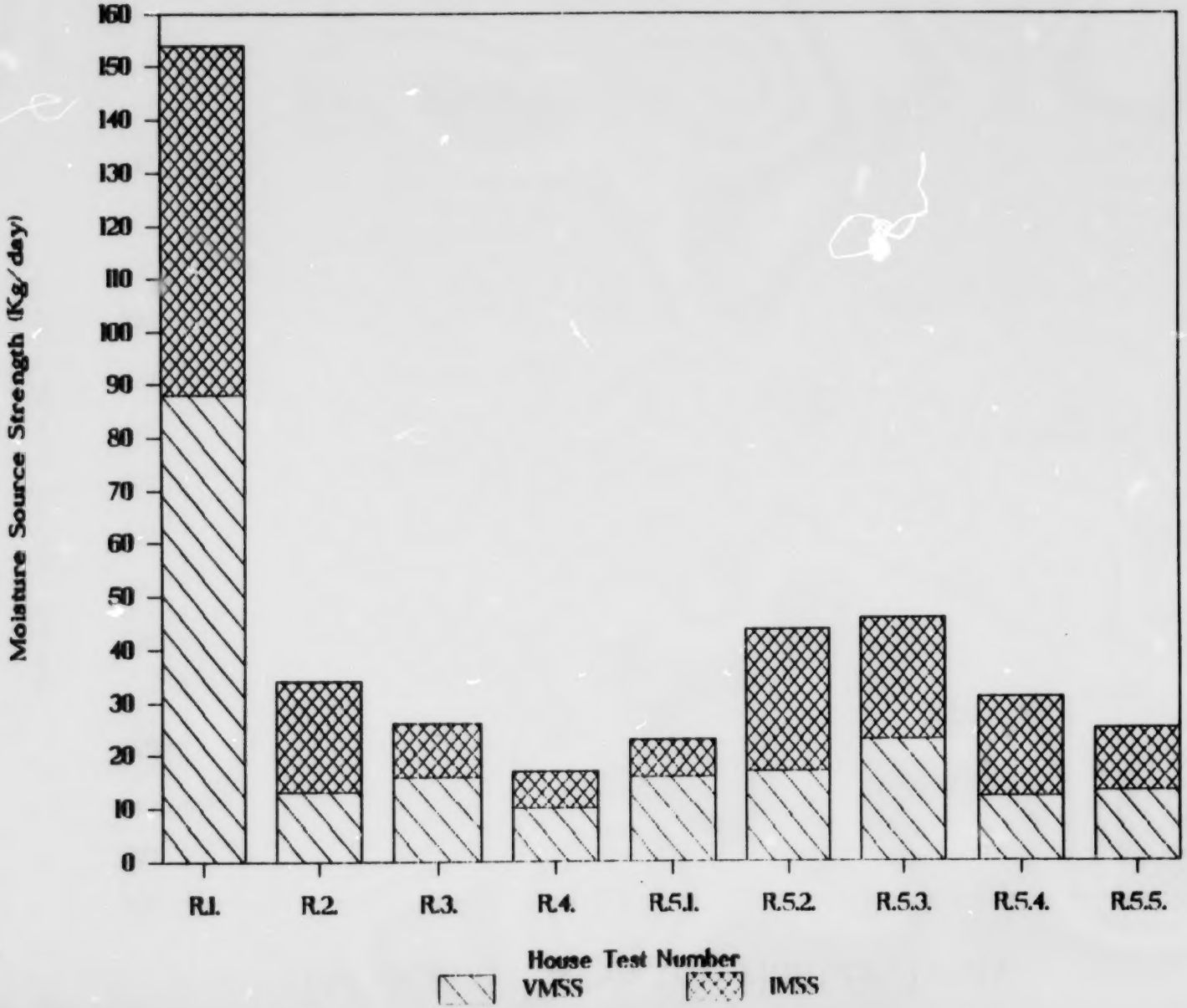


Figure 8

IMSS and VMSS for Halifax Tests

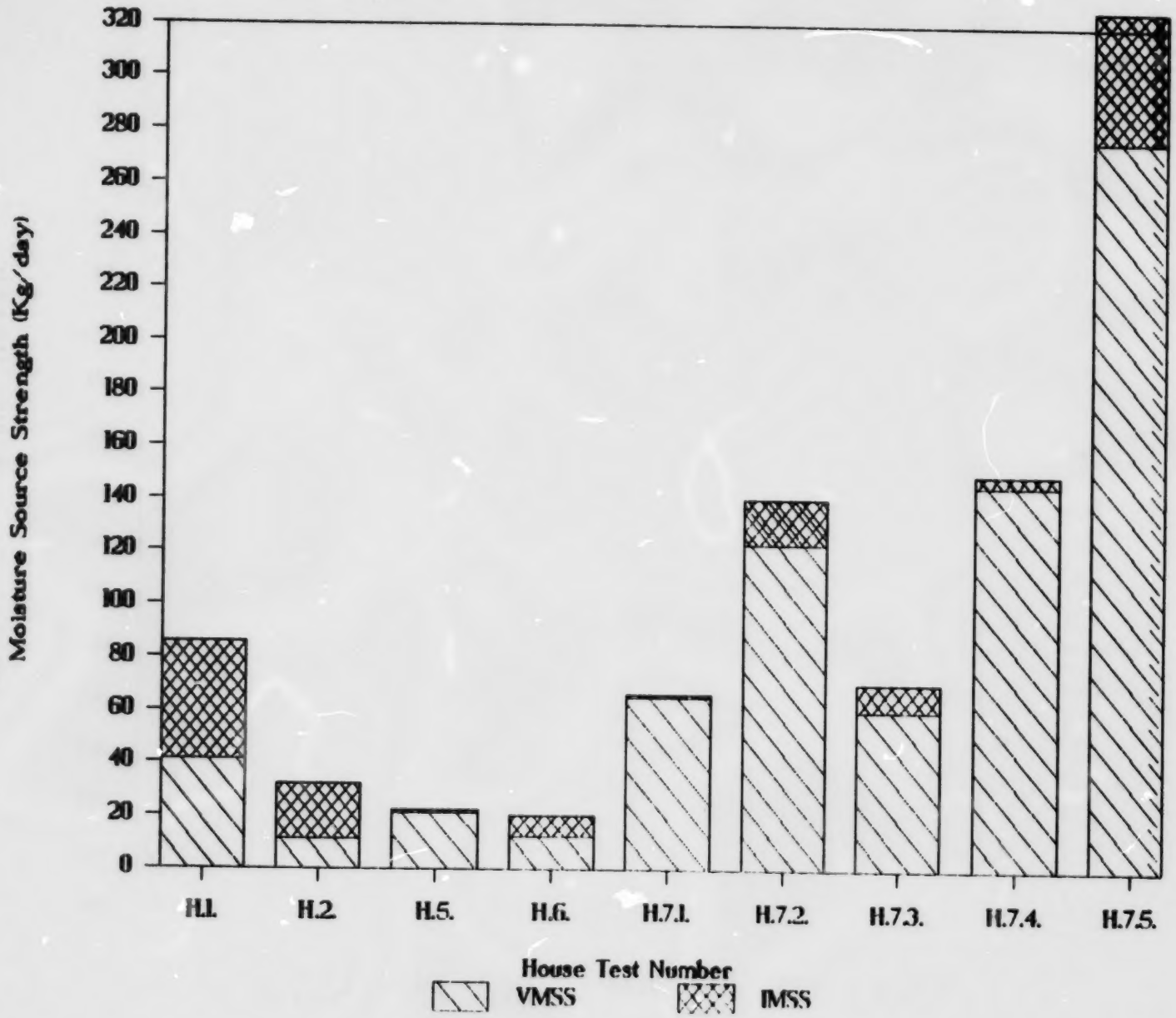


Figure 9

3.3 Distribution of Moisture Source Strength per Floor

The accompanying graphs (Figures 10 - 15) plot ACR against IMSS and TMSS for the basement, the main floor and the second floor (or another main floor location if the house does not have a second storey). The graphs show the same linear trends seen in previous graphs. The average IMSS and TMSS values by location are as follows:

Location	ACR	IMSS	TMSS
Basement	28.6	8.77	19.12
Main Floor	22.3	5.77	14.65
Main/Second Floor	27.8	9.54	21.94

One would expect that the basement values should be the highest on average because the basement normally is supplying air (and moisture) for the other two floors through stack action. The fact that the flue was not sealed should also contribute to higher basement values as well.

There are a number of reasons for this result.

1. Many of the houses such as those on the coast are electrically heated and therefore do not have flues.

2. There are some houses in the analysis which are not two storey houses. However one would expect that the basements values should be higher for bungalows and bi-levels as well as two storeys. The one slab-on-grade house was eliminated from the analysis.
3. One reason for the higher basement values would be that air enters the house at the foundation. If the foundation is of beam-fill construction (joists cast into the foundation wall), there would not be a great deal of air infiltration at this point. Other foundation construction practices will of course result in much greater infiltration at the foundation and should in turn likely raise moisture source strength in the basement.

Another way of analysing the floor by floor data would be to compare IMSS and TMSS per floor with wind conditions. One might expect that variations in IMSS and TMSS would be less pronounced when a house was subjected to wind effect. The data shows no relationship between moisture source strength and wind loadings on the test houses. One reason for not observing this effect may relate to the small sample size. Wind conditions did vary dramatically especially in the coastal areas and these changing wind conditions were not recorded during the test. The effect of wind is also dependent upon the presence of trees and other buildings which need to be more accurately recorded.

Air Leakage Rate vs IMSS (Loc 1)

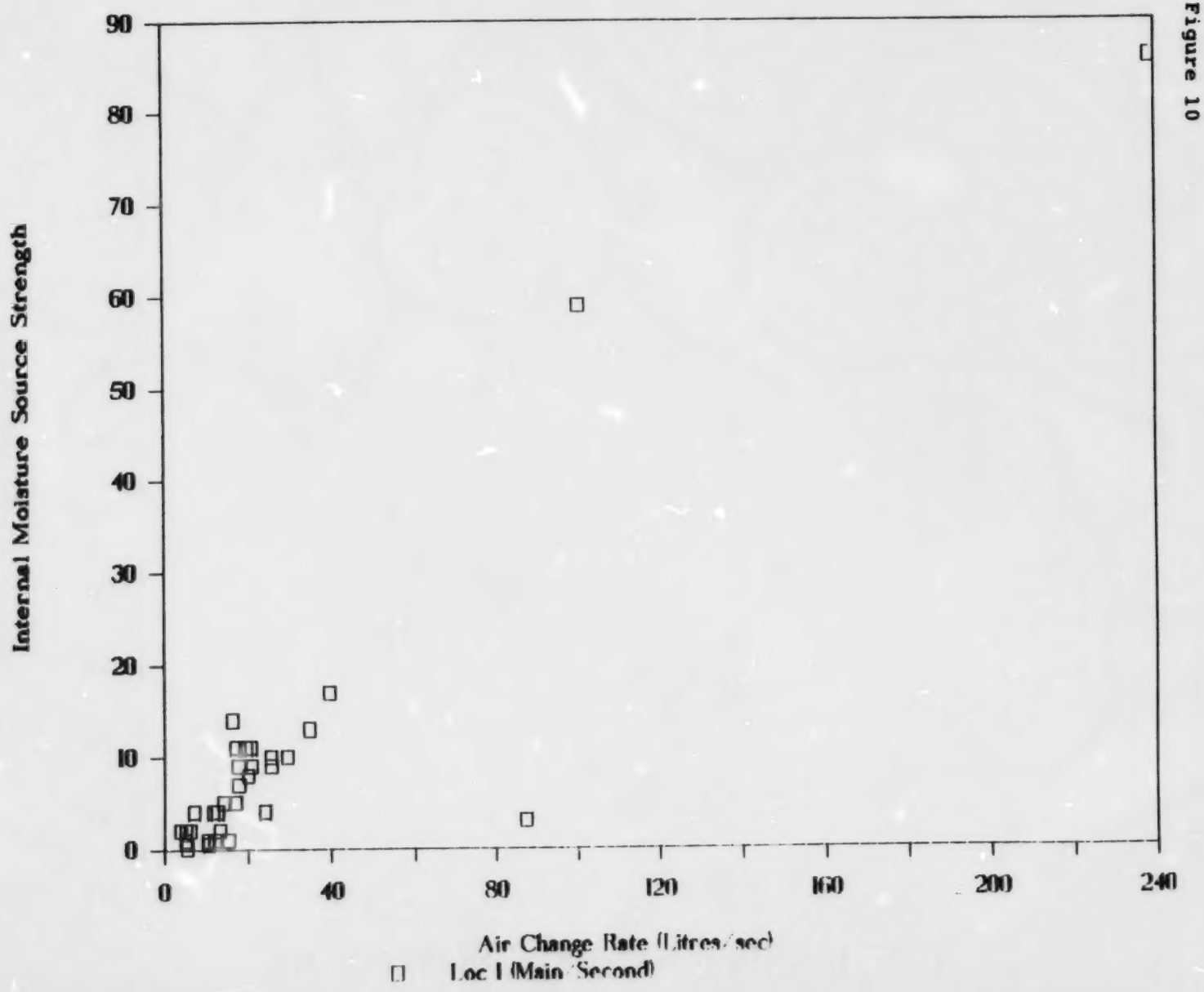


Figure 10

Air Leakage Rate vs TMSS (Loc 1)

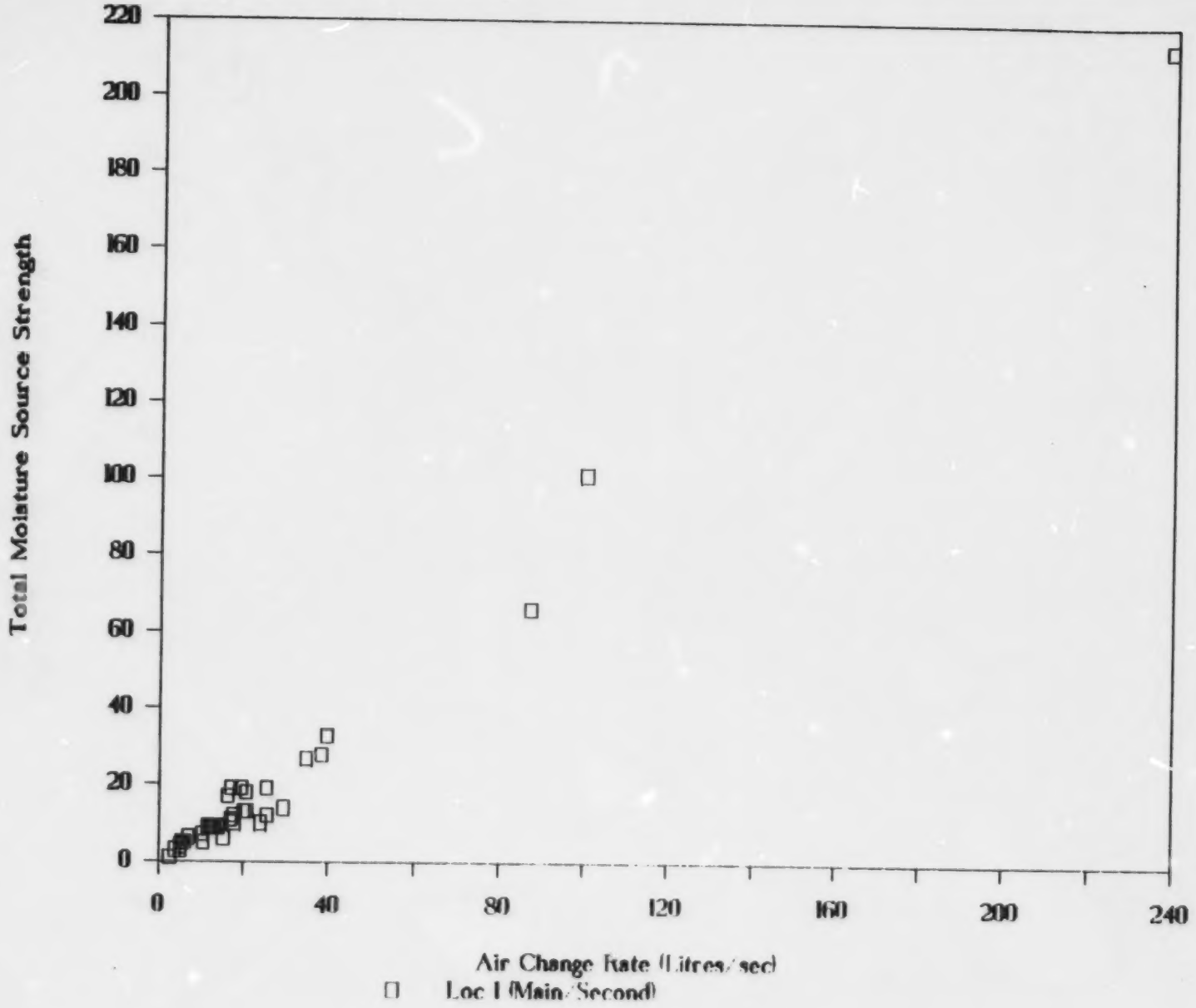


Figure 11

Air Leakage Rate vs IMSS (Loc 2)

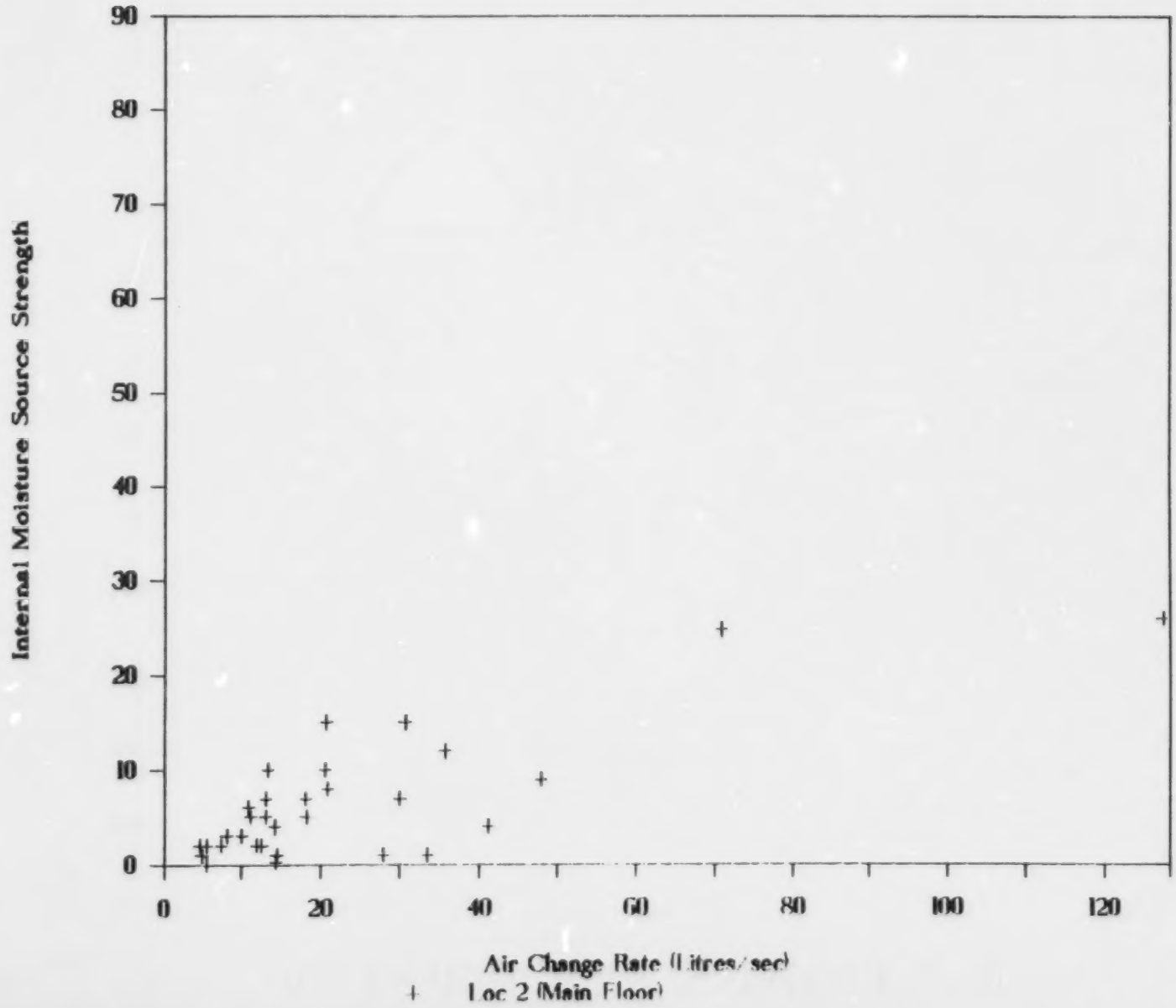


Figure 12

Air Leakage Rate vs TMSS (Loc 2)

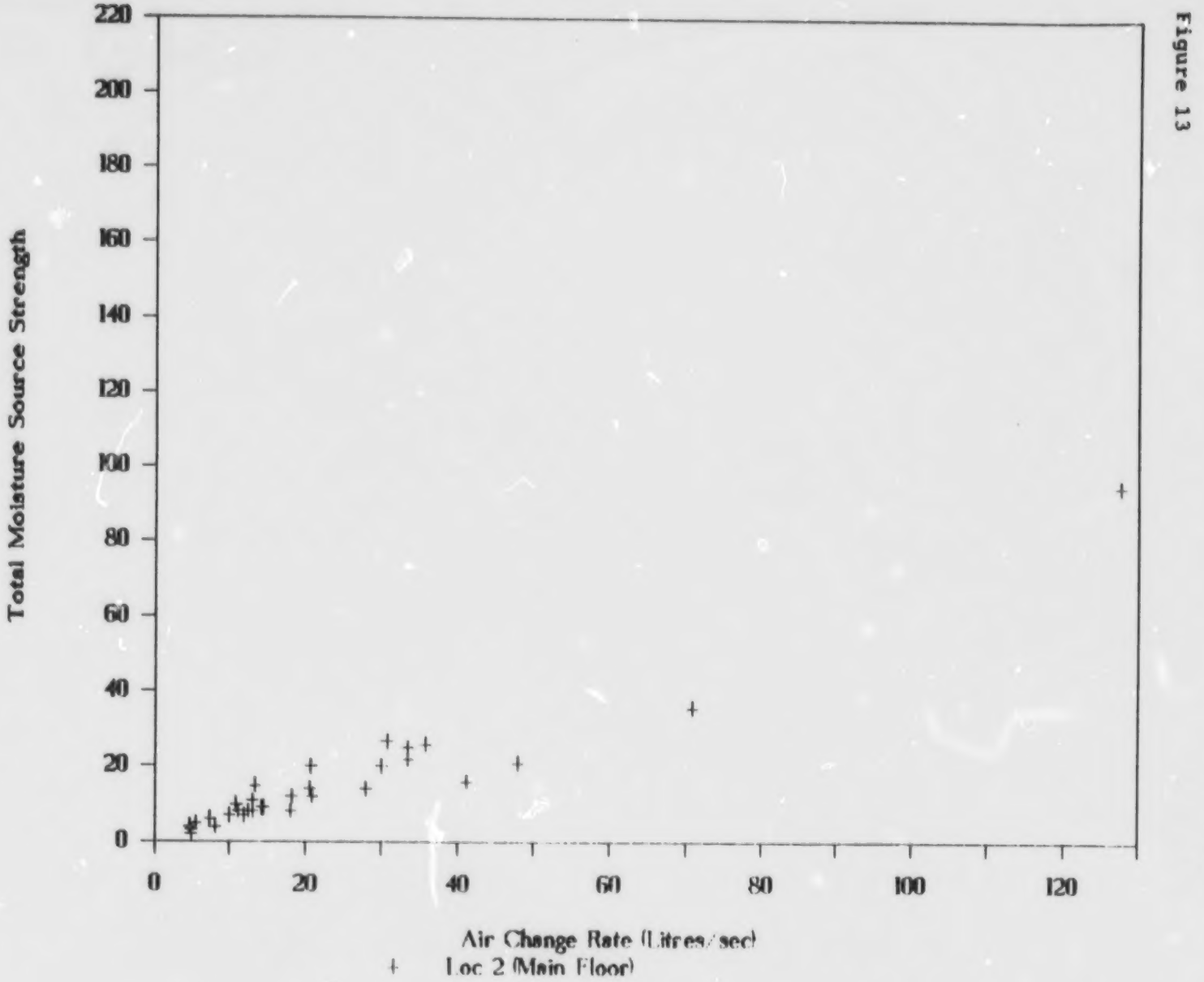


Figure 13

Air Leakage Rate vs IMSS (Loc 3)

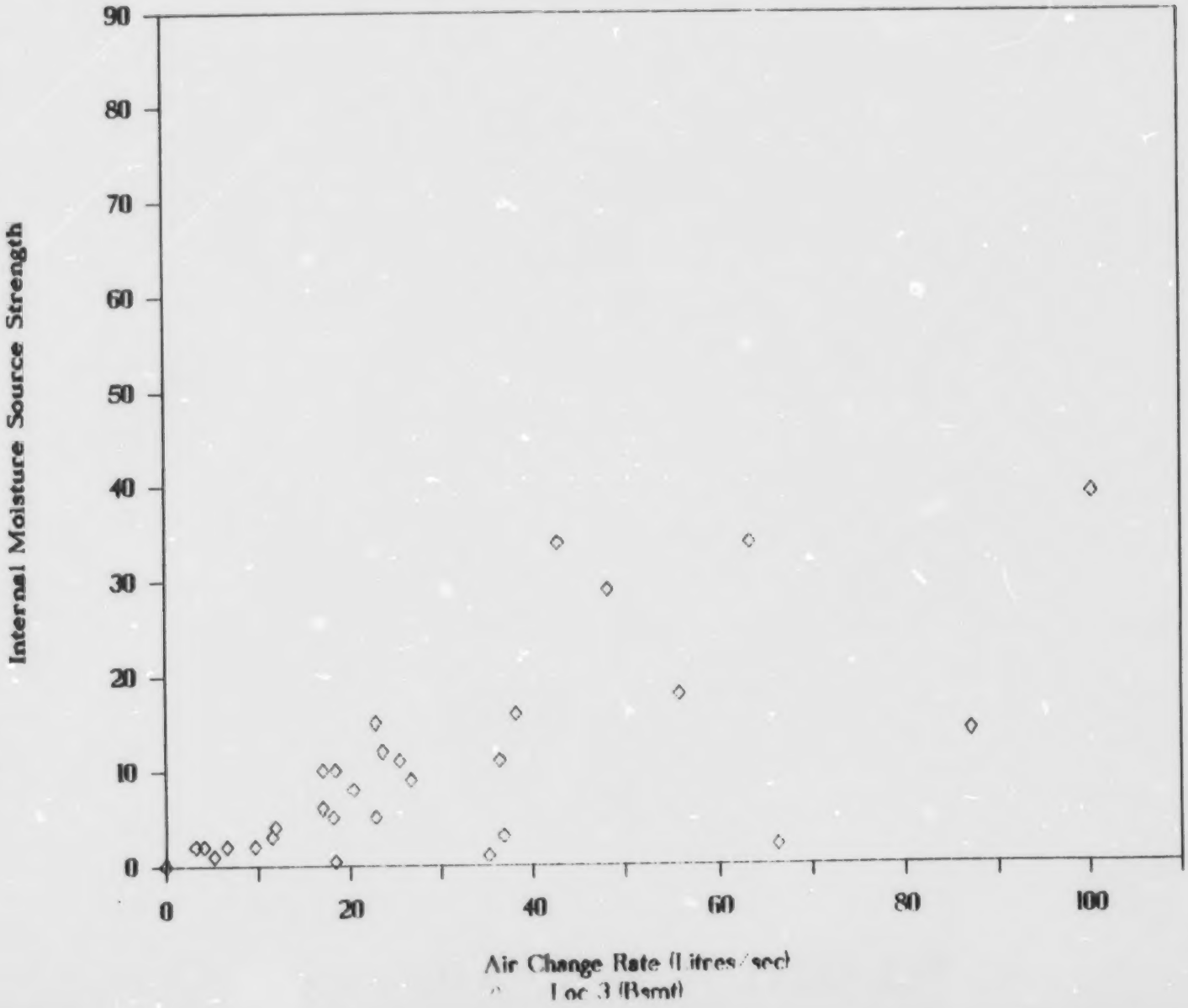


Figure 14

Air Leakage Rate vs TMSS (Loc 3)

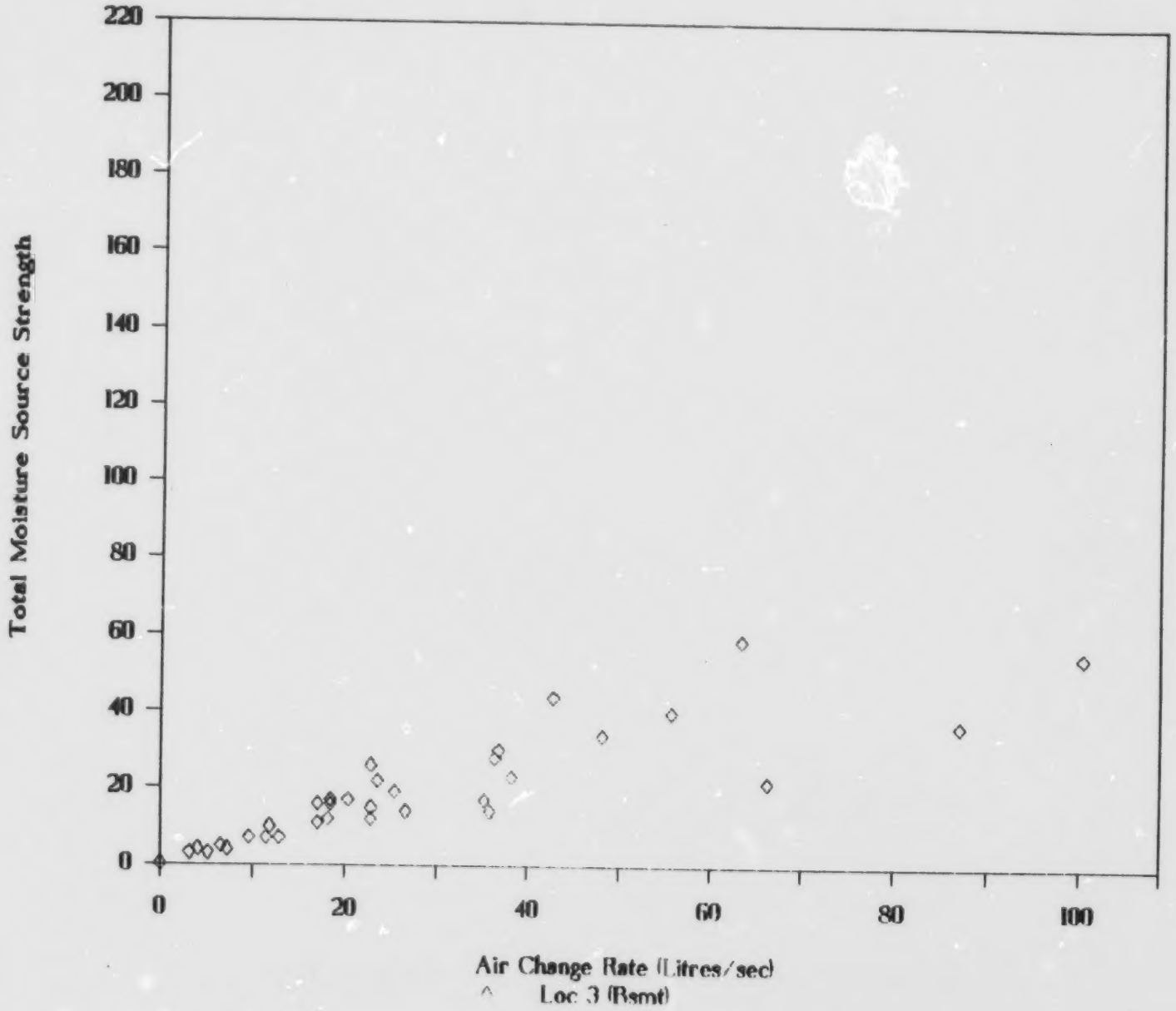


Figure 15

3.4 Correlation of Data with Other Trends

The Team looked for trends in the data to see if any correlation could be found. The Team graphed the following:

ACR vs Tout-Tin

ACR vs TMSS/IMSS

AHo vs TMSS

AHo vs IMSS

AHo vs Tout-Tin

The Team graphed ACR and AHo against wind speed but found no useful results so these graphs were not produced. A brief explanation of the graphs is offered.

ACR vs TMSS/IMSS Ratio (Figure 16)

The ratio of IMSS to TMSS shows that this is another way of representing the contribution to the total moisture load made by the house (including the occupants, soil surrounding the foundation and storage effects from building materials). Thus:

$$TMSS = 86{,}400 \times ACR \times \frac{(AHi)}{SV}$$

$$IMSS = 86{,}400 \times ACR \times \frac{(AHi - AHo)}{SV}$$

Calculating ratios

$$\frac{TMSS}{IMSS} = \frac{AHi}{AHI - AHO}$$

The ratio is simply the ratio of absolute humidities.

The average ratio is 3.76 and this result generally does not vary regardless of air change rate. The ratio between IMSS and VMSS is about 27:73 suggesting that VMSS is about three times the IMSS.

ACR vs Tin-Tout (Figure 17)

The average Tin-Tout is about 15.6°C. The graph shows little useful relationships.

AHo vs Tin-Tout (titles as T diff) (Figure 18)

The graph suggests an inverse relationship. As Tin is more or less constant the larger the Tin-Tout the colder it is outdoors and the lower the AHo.

AHo vs IMSS (Figure 19)

The data shows a slight inverse relationship which is a similar finding to the BEST Study Figure 3.3. (reproduced as Figure 20 in this report). As AHo decreases, the IMSS increases. This is likely because the outside air which enters into the house is dry so the vapour pressure differential is increased and

moisture migrates from the foundation walls or released from building materials to the house atmosphere.

AHo vs TMSS (Figure 21)

There was no correlation between AHo and TMSS because TMSS does not change as AHo changes. TMSS remains constant because as VMSS falls IMSS rises in value.

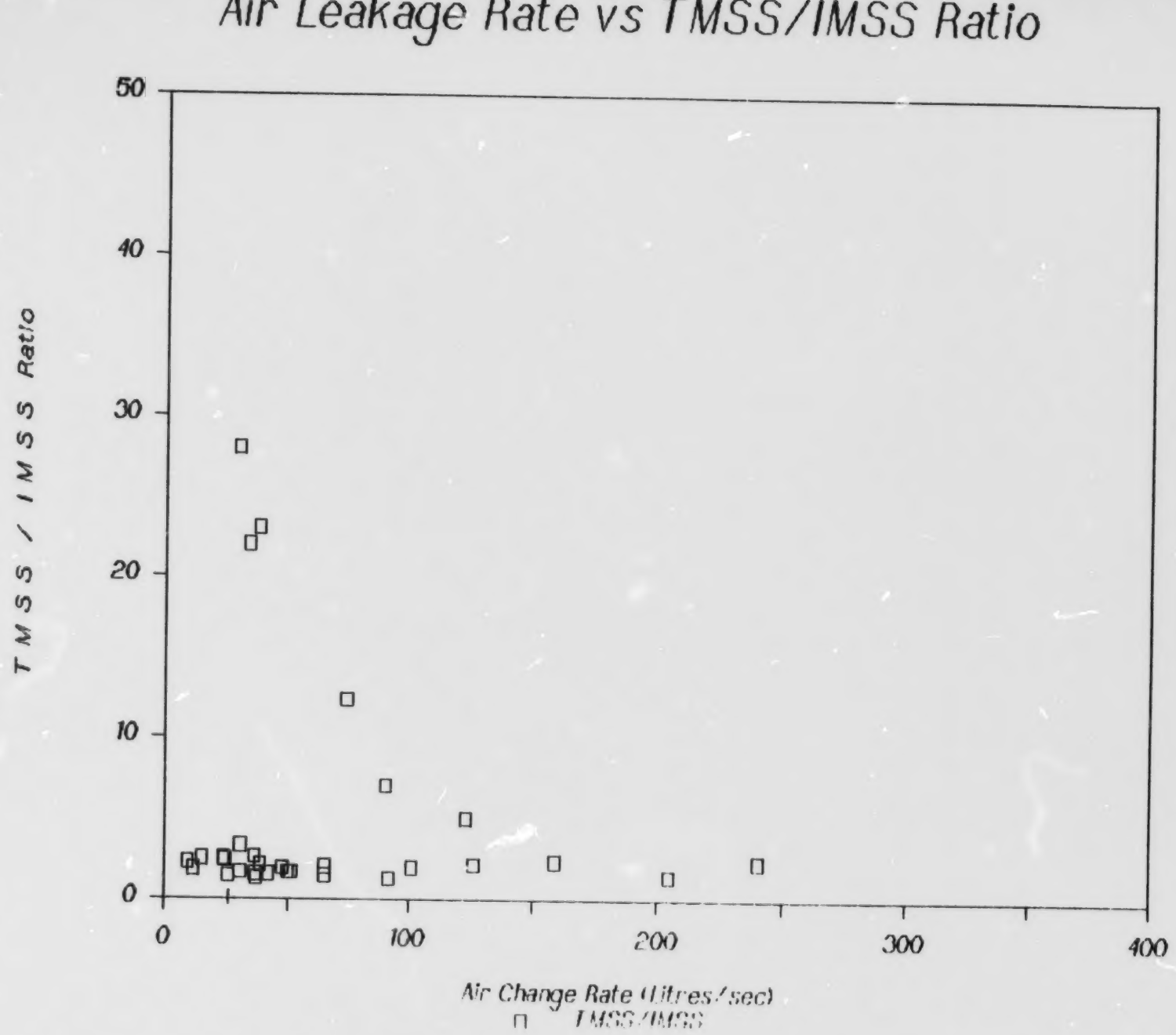

Air Leakage Rate vs TMSS/IMSS Ratio
50
40
30
20
10
0
TMSS / IMSS Ratio
0
100
200
300
400
Air Change Rate (Litres/sec)
TMSS/IMSS

Figure 16

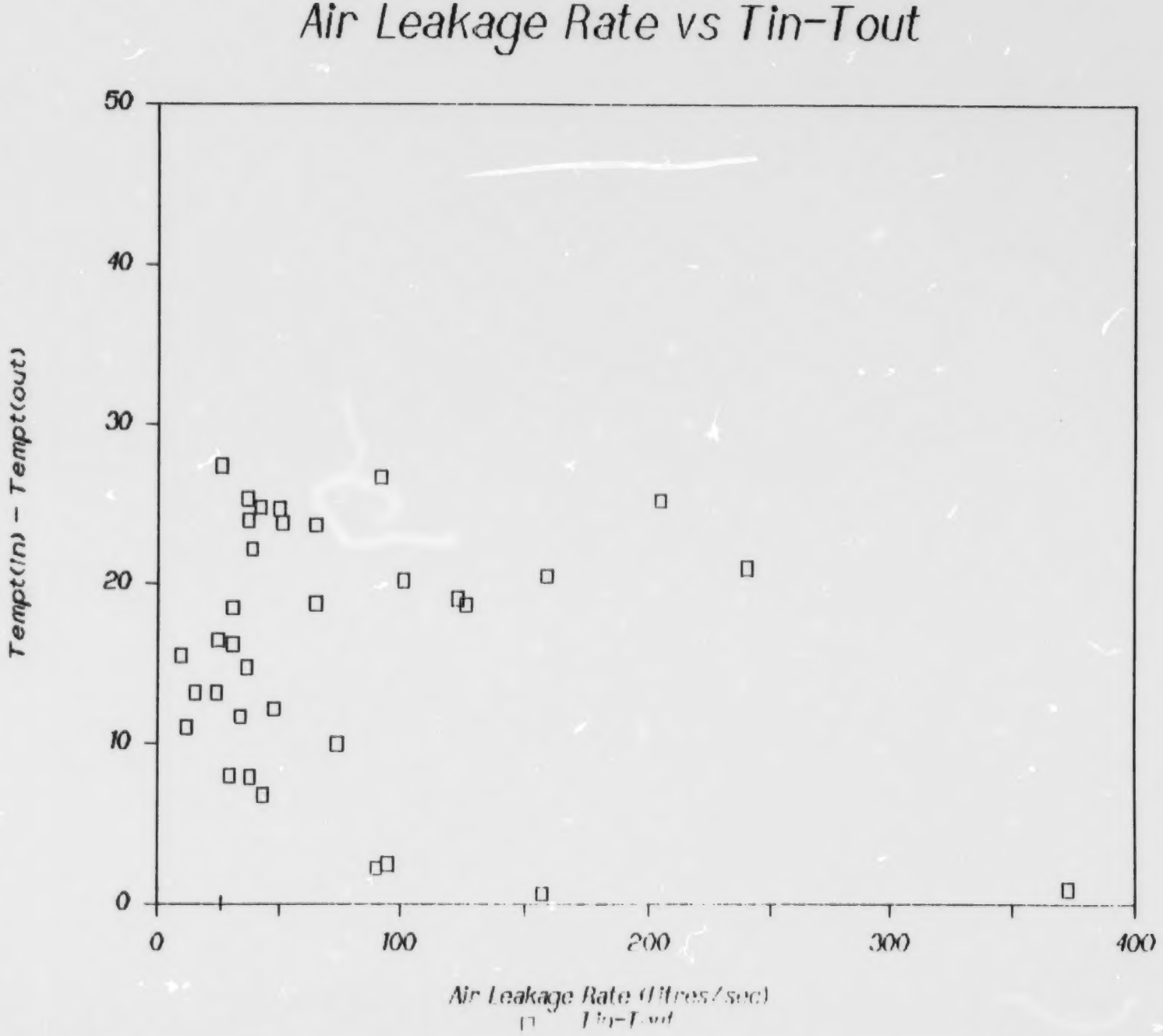

Air Leakage Rate vs Tin-Tout
Temp(in) - Temp(out)
50
40
30
20
10
0
0
100
200
300
400
Air Leakage Rate (litres/sec)
Tin-Tout

Figure 17

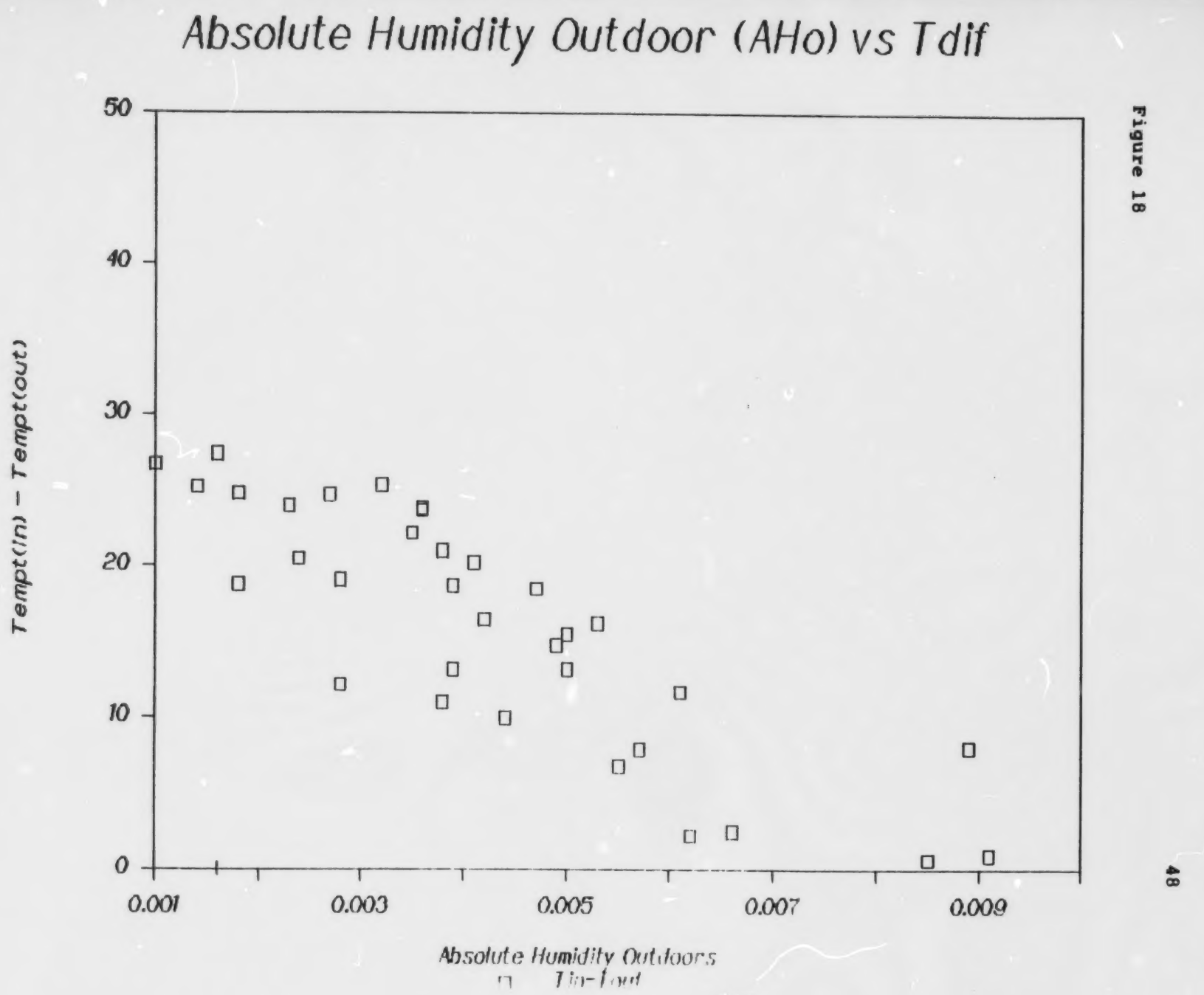

Absolute Humidity Outdoor (AHo) vs Tdif
50
40
30
20
10
0
Tempt(in) - Tempt(out)
0.001
0.003
0.005
0.007
0.009
Absolute Humidity Outdoors
Tin-Tout

Figure 18

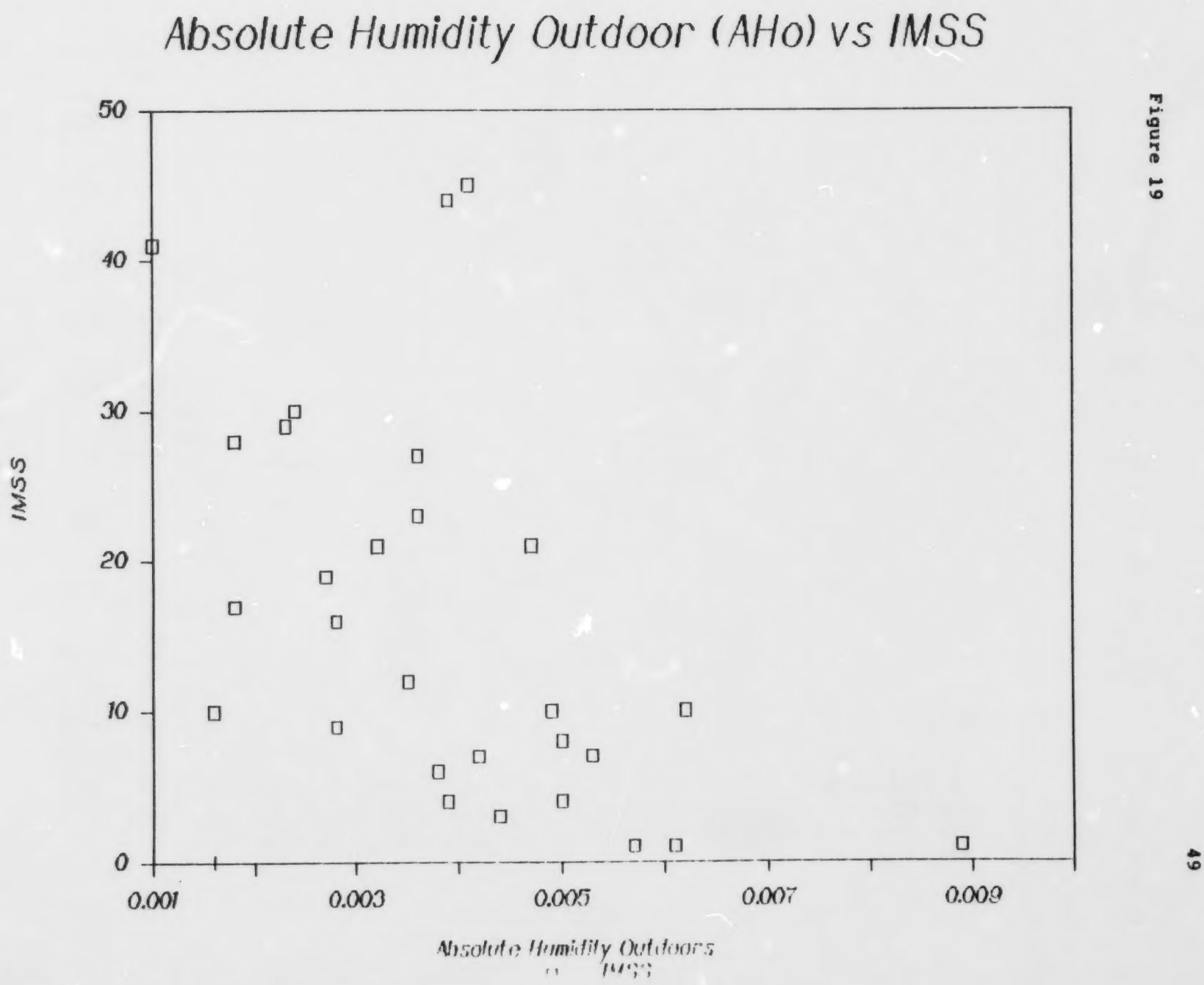
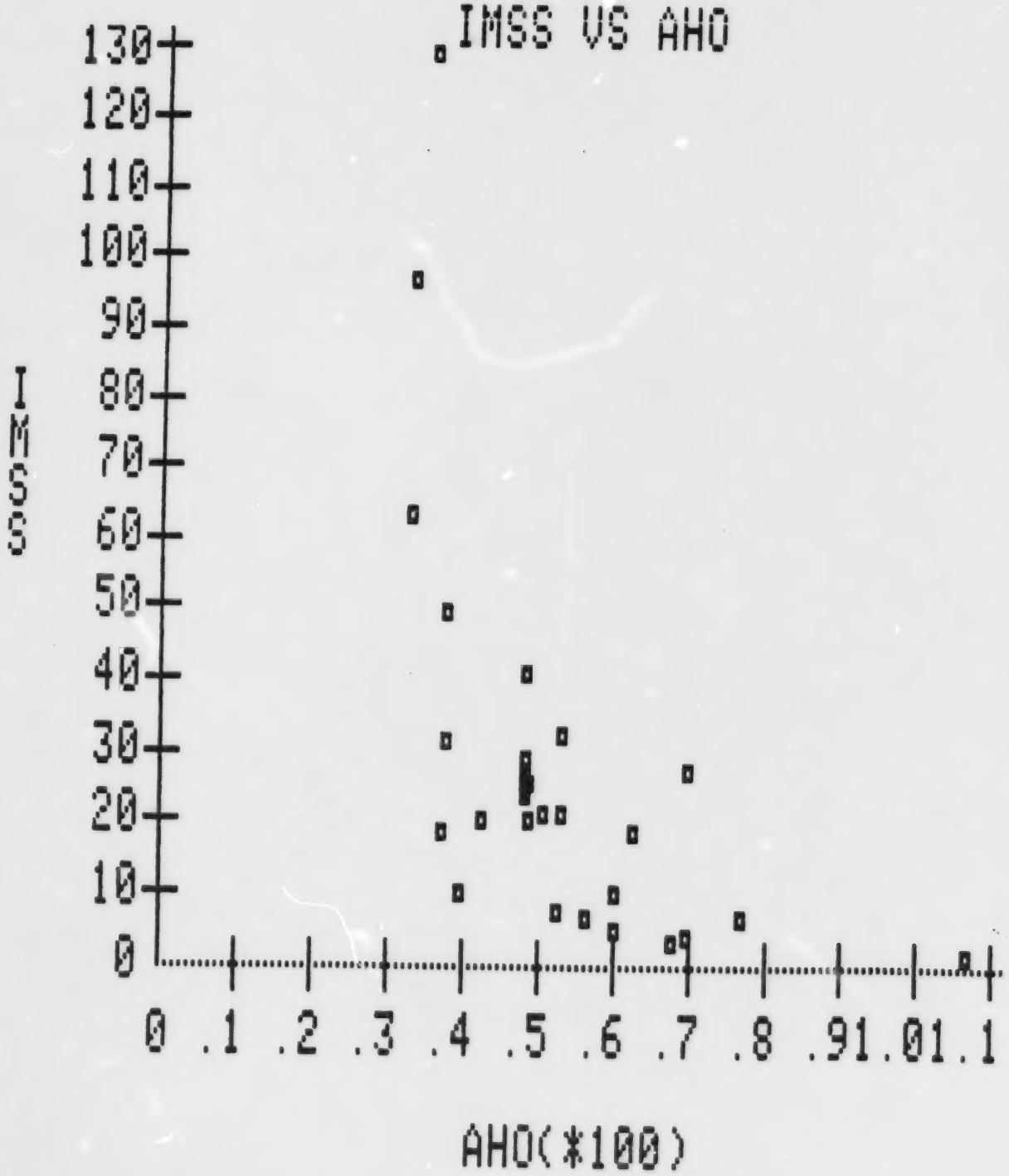

Absolute Humidity Outdoor (AHo) vs IMSS
IMSS
50
40
30
20
10
0
0.001
0.003
0.005
0.007
0.009
Absolute Humidity Outdoors
IMSS

Figure 19

Figure 20 (from "Field Trials of Test Procedures to Determine Internal Moisture Source Strength" by BEST Corporation)



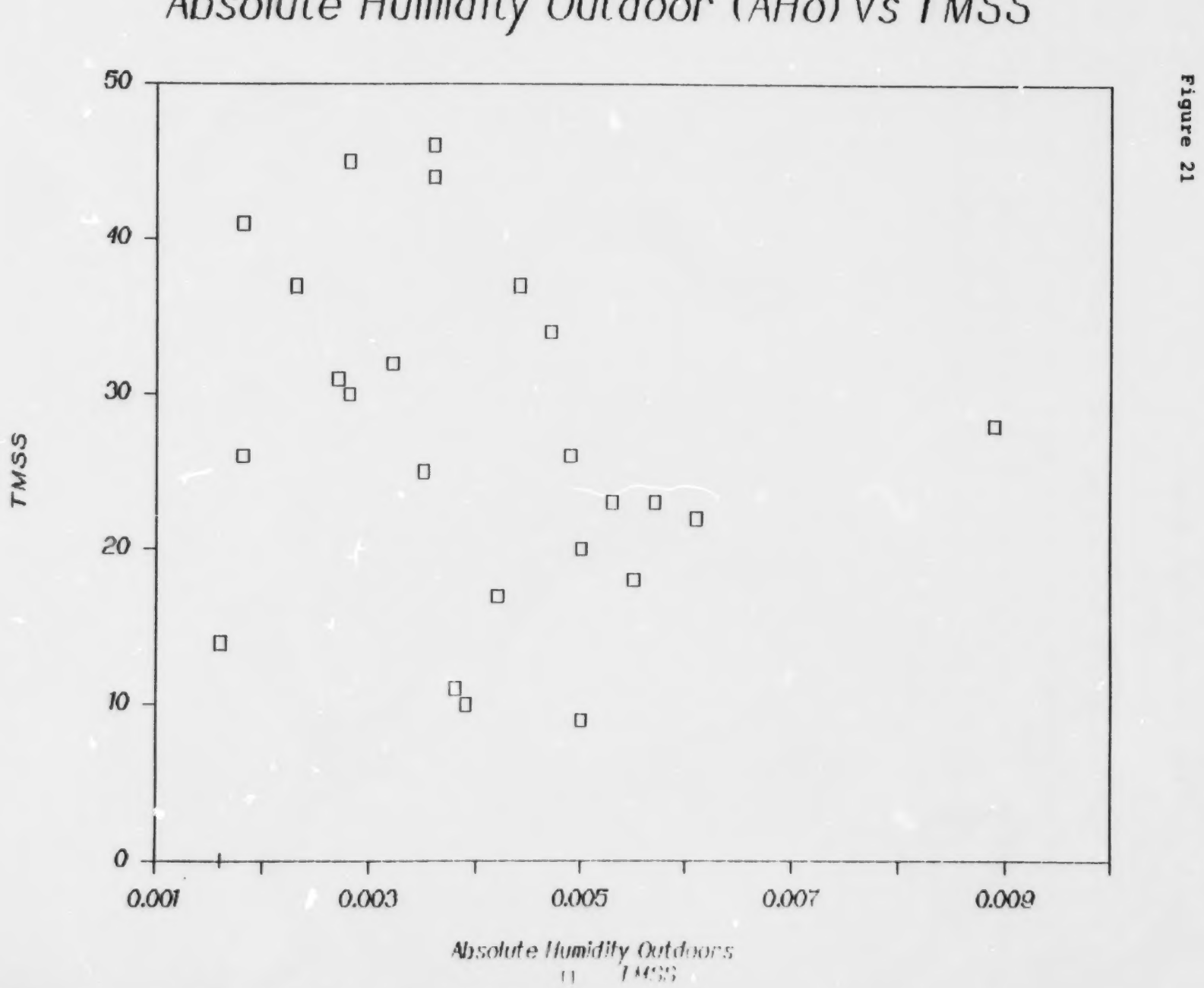

Absolute Humidity Outdoor (AHo) vs TMSS
50
40
30
20
10
0
TMSS
0.001
0.003
0.005
0.007
0.009
Absolute Humidity Outdoors
TMSS

Figure 21

3.5 Analysis of Multi-Test Houses

The Team graphed ACR and AHo against IMSS and TMSS for the multi-test houses separately and found that little information of value could be obtained because the sample sizes were too small. (See Figures 22 - 25) Other graphs produced by the Team produced similar scattergrams and were not printed.

Abs Hum Outdoors vs IMSS By City

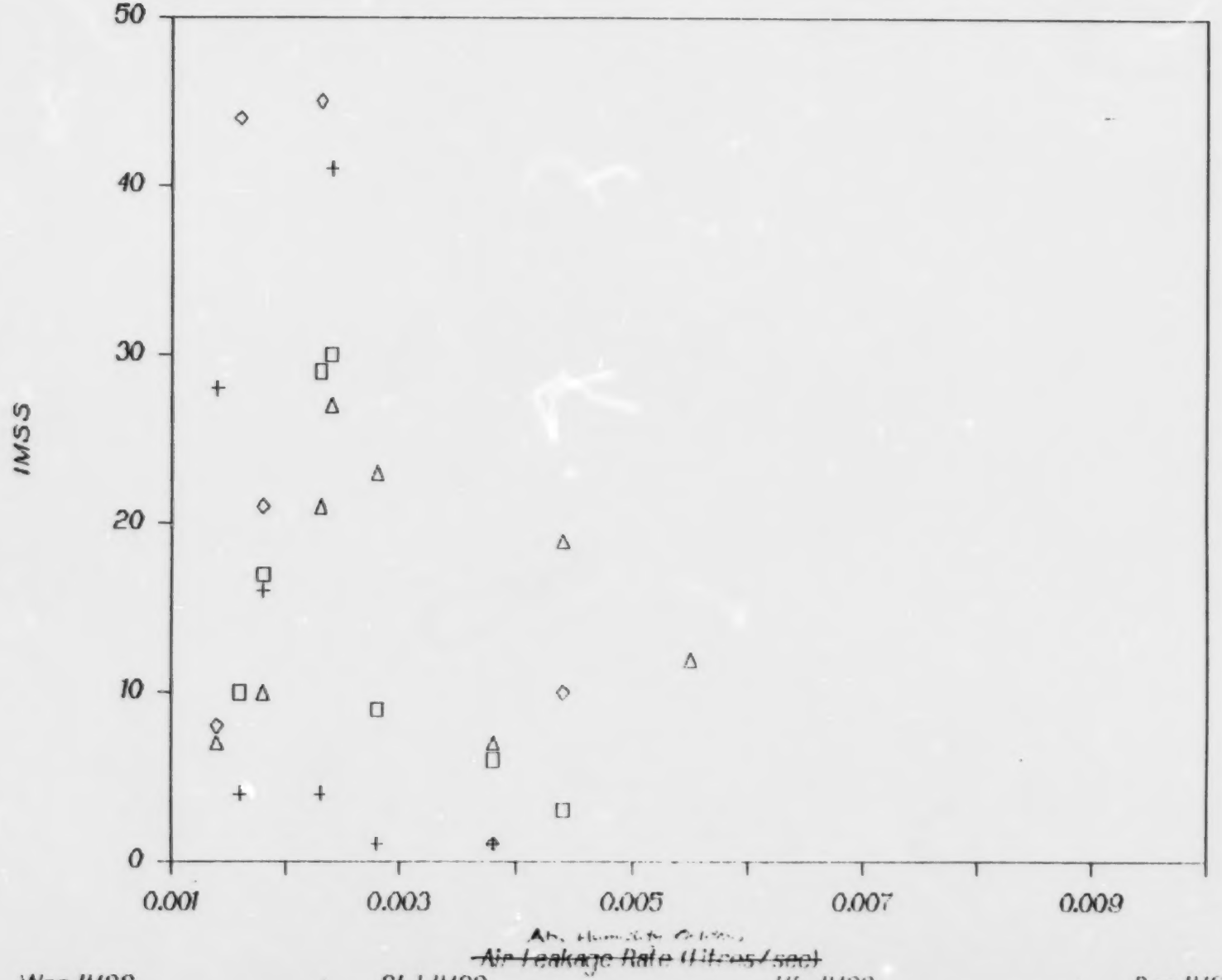


Figure 22

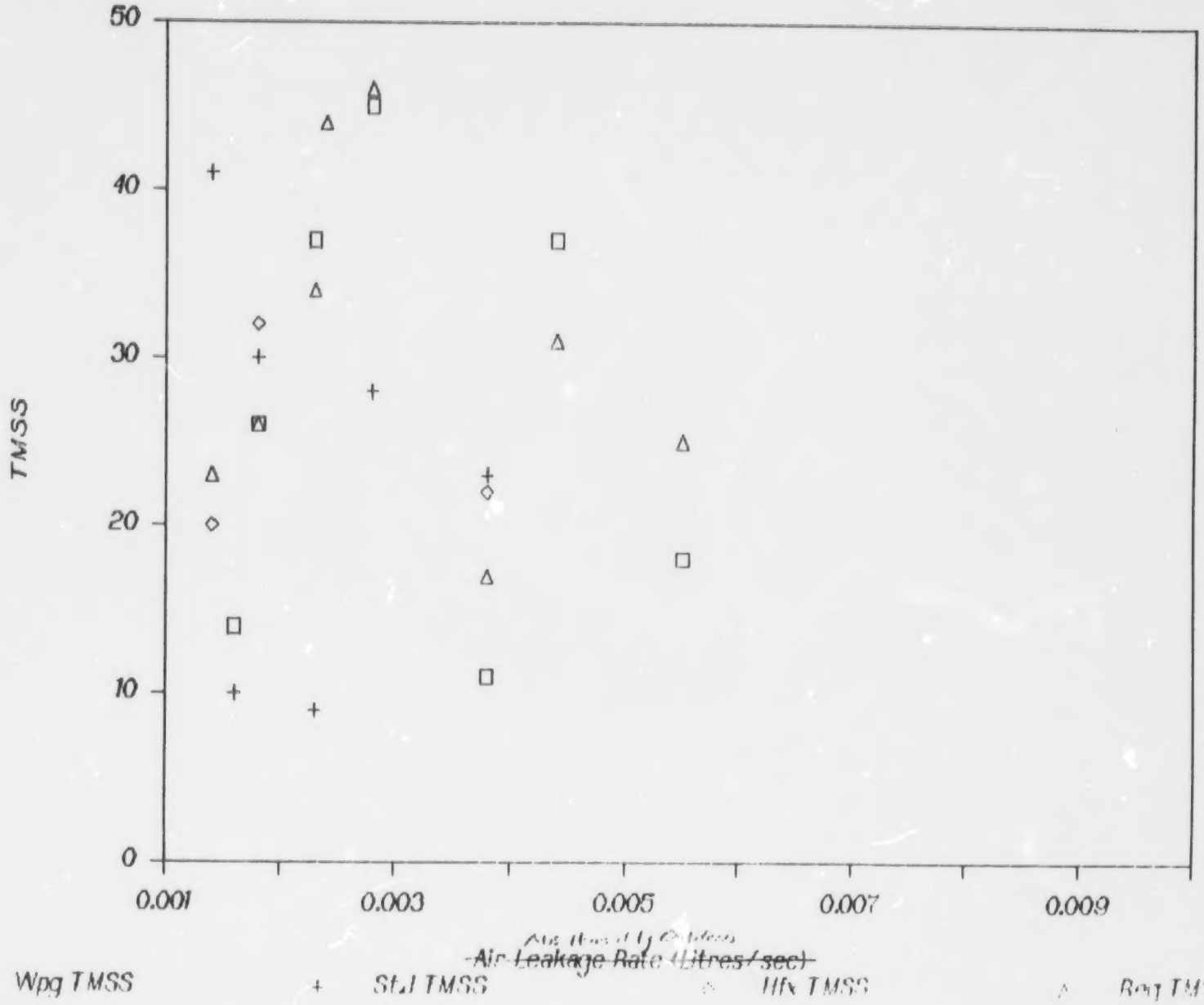

50
40
30
20
10
0
TMSS
0.001
0.003
0.005
0.007
0.009
Air Leakage Rate (Litres/sec)
Wpg TMSS
Stl TMSS
Hfx TMSS
Reg TMSS

Figure 23

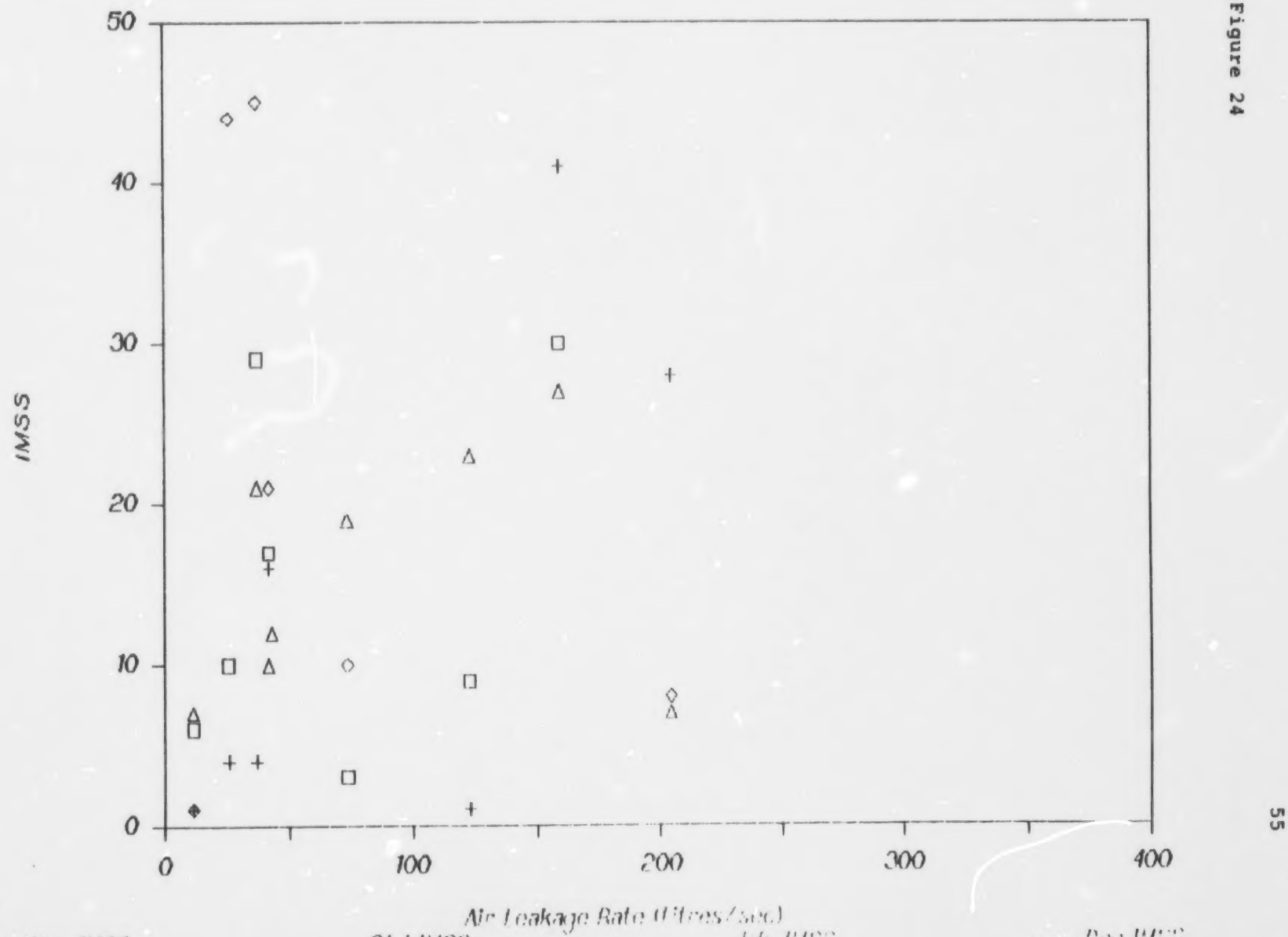

Air Leakage Rate vs IMSS By City
IMSS
50
40
30
20
10
0
0
100
200
300
400
Air Leakage Rate (Litres/sec)
Wpg IMSS
SLJ IMSS

Figure 24

Air Leakage Rate vs TMSS By City

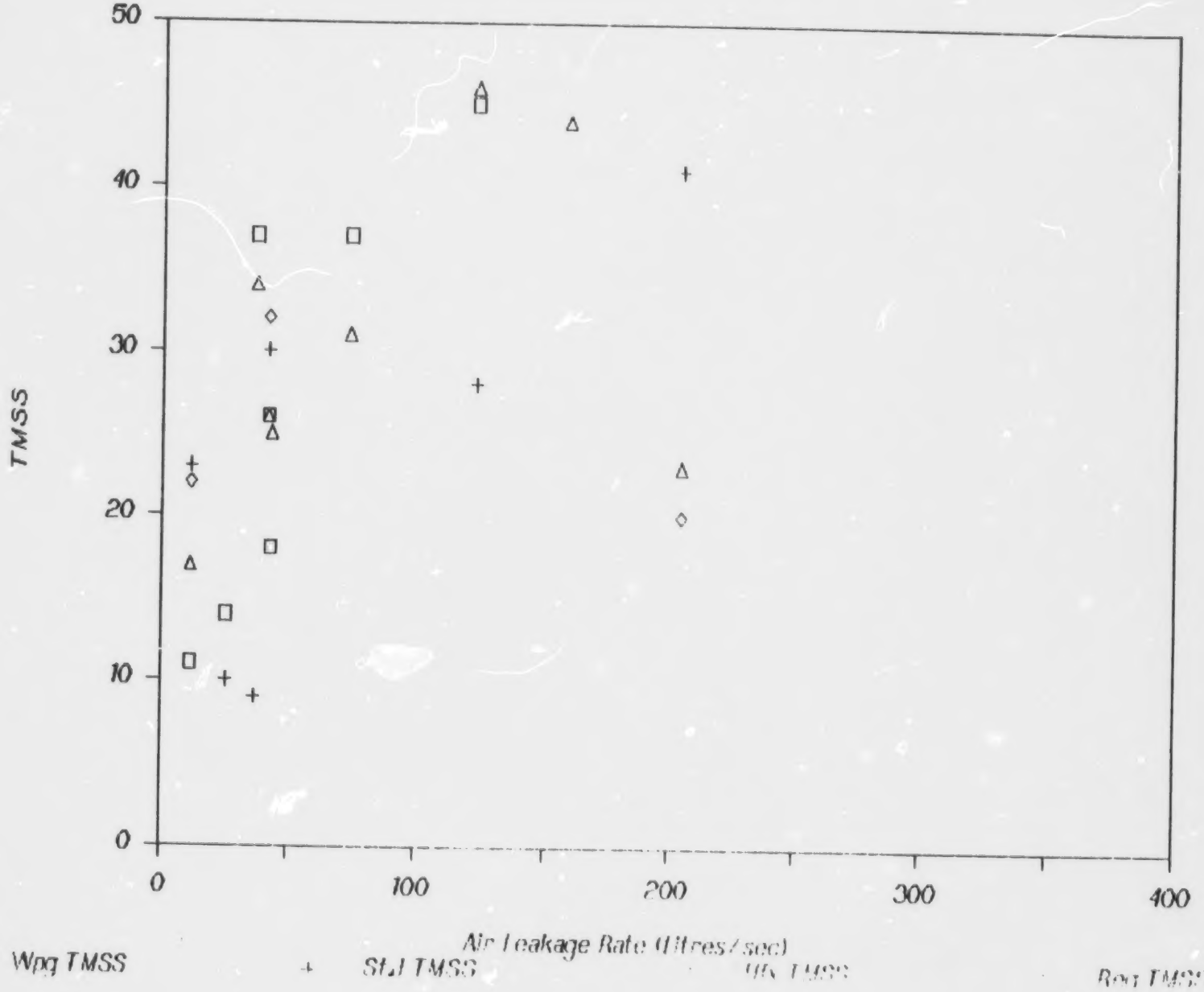


Figure 25

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

It is difficult to draw definitive conclusions from such a small sample of houses. Moisture problems are highly individualized. However there are some specific observations which can be made.

1. The data for TMSS and IMSS does vary dramatically from house to house and within the multi-test houses. The data does show that one can correlate ACR, TMSS and IMSS with moisture problems found in the house. If a house is tight, it can generally tolerate less moisture before problems begin to appear.

2. While the results show much greater control over moisture movement in modern energy-efficient houses more testing needs to be done before one can, with confidence, relate the test results to changes in outdoor ambient conditions or to normal moisture generating sources indoors.

3. The average values for IMSS, VMSS and TMSS were 15, 40 and 55 Kg/day respectively. The quantities of moisture processed by a house are generally three times greater

than the amount usually generated indoors. The hypothesis that house storage could account for 80% of IMSS with people and their activities accounting for the balance could not be proved or disproved.

4. The data shows that the problem houses generally have the following characteristics.

   1. IMSS is equal to or exceeds VMSS
   2. The house is relatively air tight
   3. The design is such that the house is incapable of processing moisture.

   One reason why moisture troubled houses display the result that IMSS is equal to or exceeds VMSS might be that houses are capable of processing much moisture from ventilation sources. High IMSS values only serve to compound the moisture problem for the house. However for the moisture problems to appear in a house, it must be relatively tight and/or have design problems which make the house susceptible to moisture (i.e. air leaks into the attic, exposed soil in the basement, no ventilation system).

5. The linear relationship between Air Change Rate (ACR) and IMSS and TMSS is consistent with the findings of

BEST. This means that as ACR increases so does IMSS and TMSS. The inverse trend between Absolute Humidity Outdoors (AHo) and IMSS was similar to that found in BEST. This means that as the moisture level of outside air decreases, the rate of internal moisture generation increases.

6. The Team found that there were a few negative values for IMSS. This means that the house is actually absorbing rather than releasing moisture. The results occurred in two of the leaky and moisture troubled houses. These results are very dependent upon the measure or selection of the correct RHo as the Team found for the Halifax house when the RHo from the weather station was used the IMSS was not negative because the weather station RHo was much lower than the RHo measured at the house.

7. The Team could find little correlation between ACR and AHo with such data as Tin - Tout, TMSS/IMSS and wind speed.

8. When the IMSS and TMSS data were graphed against ACR on a floor by floor basis the same linear trends were observed. However, the basement IMSS and TMSS values were not the highest on average. The high basement

values resulted only when the foundation design allowed basement to supply air to the other floors and of the house through stack action. Where tests were done in high wind conditions, one might have expected the moisture source strengths to be equal in value but this was not the case. The reasons for this finding could be due to the small sample size and the fact that wind speed and direction (which can vary dramatically) was only recorded once.

9. The test procedure itself is subject to many problems. Two of the 37 tests could not be used because the tubes were damaged in transit. However a detailed analysis of the SF_6 concentration correlated with wind speed and direction could be explained from building physics principles such as wind and stack effect for a few houses. Measurement of RHo is critical. Given that climates can vary dramatically especially in the coastal regions, reliance on weather data for RHo may give inaccurate moisture source strength results.

4.2 Recommendations

1. As one primary goal would be to see house TMSS, IMSS and ACR can be correlated with moisture problems, efforts should be focussed on measuring houses with

moisture problems before and after corrective measures are taken. Hopefully as more data is of this nature is gathered, one would be able to know in advance from measurements of ACR using less sophisticated means (ie a door fan) and RHo and RHi using a sling psychrometer, one would be able to know whether or not a house has serious levels of IMSS or VMSS.

The Team suggests that if further tests are to be done on these houses, testing with a door fan, the SF_6 process and an ambient air analyser such as a Miran 1-B be done simultaneously. While a Miran is extremely expensive to use, one gets instant results. Samples are not sent to a lab for analysis so there is no problem of damage in transit or at the lab. A correlation of the three procedures would prove useful as it would verify whether or not a door fan can be used in making moisture measurements.

Measurement of ELA and collection of wind and shielding coefficients need to be collected for each house would allow for the calculation of a flow rate due to natural infiltration to be calculated. This could be used as the ACR value. If RHo and RHi is also measured one can calculate IMSS, VMSS and TMSS. These values will not be as accurate as with the SF_6 or Miran tests but could

serve as a simplified procedure for measuring moisture source strength.

2. If the simultaneous testing process shows that the data can be collected using simplified means, this data, when used in conjunction with a simple moisture source checklist or pre-test of the type that Scanada is developing for EMR, will allow a contractor to assess a house with moisture problems at present or to assess the potential for future moisture problems before contemplating work such as air sealing, insulation or other work which may tighten the structure.

3. The SF_6 test procedure itself needs to be refined. The measurement of RHo and wind is critical and needs to be more rigorously defined. Use of weather data especially in coastal regions should be replaced by actual measurements near the house. Weather data should only be used as a check against actual data measured at the house.

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APPENDIX 1

DETAILED DATA

MOISTURE SOURCE STRENGTH SUMMARY SHEET. DATE: 31-May-87

HOUSE NUMBER & TEST	LOCATION NUMBER	LOCATION (See Code	SHARE OF VOLUME	TEST AREA VOLUME (m3)	I N P U T S AIR CHANGE (-)	AMBIENT PRESSURE (kPa)	TEMPERATURE(C) INDOOR IAT	TEMPERATURE(C) OUTDOOR OAT	RELATIVE HUMIDITY(-) INDOOR RHI	RELATIVE HUMIDITY(-) OUTDOOR RHO
H.1	1	M.Lr.NW	0.25	99	0.7	97.9	22.8	1.7	55	91
	2	M.Kit.C	0.25	99	0.66	97.9	18.9	1.7	46	91
	3	B.Fr.C	0.5	198	1.15	97.9	23.9	1.7	49	91
	Whole house			396	0.9163636	97.9	21.9	1.7	50	91
H.2	1	M.Kit.C	0.25	89	0.29	99.5	23.3	-2.8	45	100
	2	M.Bd.E	0.25	89	0.44	99.5	21.7	-2.8	54	100
	3	B.U.C	0.5	179	0.37	99.5	22.5	-2.8	50	100
	Whole house			357	0.37	99.5	22.5	-2.8	49.7	100
H.5	1	M.Dr.SE	0.25	101	0.43	99.5	19.4	6.1	48	100
	2	M.Br.NW	0.25	101	0.51	99.5	18.3	6.1	46	100
	3	B.Fr.C	0.5	203	0.13	99.5	15.6	6.1	50	100
	Whole house			405	0.3	99.5	17.8	6.1	48	100
H.6	1	M.Kit.W	0.25	97	0.23	99.5	16.7	3.3	65	100
	2	M.Bd.SE	0.25	97	0.2	99.5	16.7	3.3	74	100
	3	B.Bd.SE	0.5	194	0.22	99.5	16.1	3.3	69	100
	Whole house			388	0.22	99.5	16.5	3.3	69.3	100
H.7.1	1	S.Bd.N	0.34	251	0.55	101.57	13.3	10.6	72	88
	2	M.H.C	0.34	251	0.48	101.57	15	10.6	58	88
	3	B.U.S	0.32	236	0.35	101.57	11.1	10.6	76	88
	Whole house			739	0.46	101.57	13.1	10.6	68.7	88
H.7.2	1	S.Bd.N		251	1.25	101.57	15	13.9	67	69
	2	M.H.C		251	0.48	101.57	15.6	13.9	64	69
	3	B.U.S		236	0.56	101.57	12.8	13.9	82	69
	Whole house			739	0.77	101.57	14.5	13.9	71	69
H.7.3	1	S.Bd.N		251	0.57	102.4	17.2	12.8	65	44
	2	M.H.C		251	0.43	102.4	12.8	12.8	67	44
	3	B.U.S		236	0.31	102.4	15	12.8	72	44
	Whole house			739	0.44	102.4	15	12.8	68	44
H.7.4	1	S.Bd.C		251	1.44	102.5	18.9	18.3	70	30
	2	M.H.C		251	0.44	102.5	18.9	18.3	62	30
	3	B.U.C		236	0.36	102.5	16.6	18.3	74	30
	Whole house			739	0.75	102.5	18.2	18.3	68.7	30
H.7.5	1	S.Bd.N		251	3.42	102.5	18.3	17.2	65	42
	2	M.H.C		251	1.83	102.5	18.3	17.2	54	42
	3	B.U.C		236	0.1	102.5	17.8	17.2	62	42
	Whole house			739	1.82	102.5	18.1	17.2	60.3	42
N.1	1	M.H.C	0.25	116	0.16	100	20	6	40	66
	2	M.Kit.S	0.25	116	0.15	100	19.1	6	44	66
	3	B.Fr.C	0.5	232	0.08	100	18.6	6	48	66
	Whole house			464	0.12	100	19.2	6	44	66
N.2	1	M.Lr.NW	0.26	159	0.12	98.7	12.2	4	85	95
	2	M.Bd.SE	0.26	159	0	98.7	22.8	4	50	95
	3	B.Fr.C	0.48	294	0.05	98.7	22.8	4	50	95
	Whole house			612	0.06	98.7	19.5	4	61.7	95
N.3.1	1	M.Kit.W	0.26	148	0.34	101.94	16.8	2	50	63
	2	M.Bd.NE	0.26	148	0.27	101.94	18.7	2	50	63
	3	B.U.C	0.48	274	0.3	101.94	7.1	2	77	63
	Whole house			570	0.3	101.94	14.2	2	59	63

M.3.2	1	M.Kit.W		148	0.25	99.5	16.8	7	52	89
	2	M.Bd.NE		148	0.35	99.5	17.1	7	51	89
	3	B.U.C		274	0.17	99.5	10.8	7	60	89
	Whole house			570	0.24	99.5	14.9	7	54.33	89
M.3.3	1	M.Kit.W		148	0.43	100.6	17.4	-2.8	52	57
	2	M.Bd.NE		148	0.5	100.6	18.7	-2.8	49	57
	3	B.U.C		274	0.35	100.6	11.9	-2.8	56	57
	Whole house			570	0.41	100.6	16	-2.8	52.3	57
M.3.4	1	M.Kit.W		148	0.62	101.94	17.3	-10	36	56
	2	M.Bd.NE		148	0.44	101.94	17.7	-10	35	56
	3	B.U.C		274	0.63	101.94	15	-10	62	56
	Whole house			570	0.58	101.94	16.7	-10	44.3	56
M.4	1	M.Kit.C	0.26	116	0.17	101.8	23	14.5	52	85
	2	M.H.C	0.26	116	0.17	101.8	24	14.5	47	85
	3	B.U.C	0.48	214	0.31	101.8	23.5	14.5	49.5	85
	Whole house			446	0.24	101.8	23.5	14.5	49.5	85
M.5	1	M.Kit.SE	0.35	198	0.63	101.6	21.5	2	47	87
	2	M.H.C	0.35	198	0.65	101.6	20	2	48	87
	3	B.Bd.C	0.3	170	1.18	101.6	20.6	2	45	87
	Whole house			566.5	0.8	101.6	20.7	2	46.7	87
R.1	1		0.5	283		94.43	20	-1	42	100
	2		0.5	283		94.43	20	-1	42	100
	3	B.Du.C	1	566	1.53	94.43	20	-1	42	100
	Whole house			566	1.53	94.43	20	-1	42	100
R.2	1	M.H.C	0.5	228	0.27	94.3	21.7	4	65	85
	2	B.Pr.C	0.5	228	0.21	94.3	23.3	4	62	85
	3	B.Du.C	1	455	0.18	94.3	22.5	4	63.5	85
	Whole house			455	0.24	94.3	22.5	4	63.5	85
R.3	1	M.H.C	0.36	162	0.26	94.4	21.1	6.1	48	76
	2	B.Lr.C	0.4	180	0.25	94.4	20	6.1	43	76
	3	B.Du.C	1	450	0.29	94.4	21.7	6.1	45	76
	Whole house			450	0.29	94.4	20.9	6.1	45.3	76
R.4	1	M.Lr.C	0.5	252	0.18	94.8	22.2	3	43	82
	2	B.Pr.C	0.5	252	0.17	94.8	16.7	3	49	82
	3	B.Du.C	1	503	0.13	94.8	19.5	3	46	82
	Whole house			503	0.18	94.8	19.5	3	46	82
R.5.1	1	M.Lr.SE	0.38	218	0.22	100.9	20.6	4.4	43	100
	2	S.H.C	0.24	138	0.19	100.9	20	4.4	55	100
	3	B.H.C	0.38	218	0.16	100.9	21.1	4.4	47	100
	4	B.Du.C	1	574	0.25	100.9	20.6	4.4	48.3	100
	Whole house			574	0.19	100.9	20.6	4.4	48.3	100
R.5.2	1	M.Lr.SE		218	0.34	93.9	22.2	-2	49	100
	2	S.H.C		138	0.34	93.9	22.2	-2	49	100
	3	B.H.C		218	0.29	93.9	21.1	-2	55	100
	4	B.Du.C		574	0.36	93.9	21.8	-2	51	100
	Whole house			574	0.32	93.9	21.8	-2	51	100
R.5.3	1	M.Lr.SE		218	0.42	94.43	22.2	-2	42	100
	2	S.H.C		138	0.37	94.43	21.1	-2	37	100
	3	B.H.C		218	0.42	94.43	21.7	-2	45	100
	4	B.Du.C		574	0.39	94.43	21.7	-2	41.3	100
	Whole house			574	0.41	94.43	21.7	-2	41.3	100
R.5.4	1	M.Lr.SE		218	0.33	93.77	18.3	-6	48	100
	2	S.H.C		138	0.34	93.77	18.3	-6	44	100
	3	B.H.C		218	0.28	93.77	19.4	-6	42	100
	4	B.Du.C		574	0.33	93.77	18.7	-6	44.7	100
	Whole house			574	0.31	93.77	18.7	-6	44.7	100
R.5.5	1	M.Lr.SE		218	0.28	95.17	20	-2	42	100
	2	S.H.C		138	0.26	95.17	19.4	-2	46	100
	3	B.H.C		218	0.19	95.17	21.1	-2	37	100

	4	B.Du.C		574	0.26	95.17	20.2	-2	41.7	100
	Whole house			574	0.24	95.17	20.2	-2	41.7	100
W.1	1	M.Dr.C	0.54	212	0.3	99.87	19	-8.4	39	76
	2	B.Fr.C	0.46	180	0.16	99.87	19	-8.4	36	76
	3				0.23	99.87	19	-8.4	37.5	76
	Whole house			392	0.24	99.87	19	-8.4	37.5	76
W.2	1	M.K.C	0.53	233	0.25	102.62	22.9	-2	59	69
	2	B.Fr.C	0.47	207	0.36	102.62	21	-2	60	69
	3	B.Du.C	1	439.6	0.35	102.62	22	-2	59.5	69
	Whole house			439.6	0.3	102.62	22	-2	59.5	69
W.3	1	B.Du.C	1	429	0.32	102.12	18.3	-5	44	70
	2	M.Lr.C	0.5	215	0.35	102.12	20	-5	37	70
	3	S.M.C	0.5	215	0.35	102.12	21	-5	38	70
	Whole house			429	0.35	102.12	19.8	-5	40	70
W.4*	1	M.Kit.S	0.28	56	0.25	102.08	18	7	66	61
	2	M.Lr.M	0.38	75	0.22	102.08	17.8	7	68	61
	3	M.Bd.W	0.34	67	0.17	102.08	18.3	7	68	61
	Whole house			198.41	0.21	102.08	18	7	67.3	61
W.5.1	1	B.U.C	0.34	129	2.91	101.69	12	-9	56	73
	2	M.Dr.C	0.38	145	1.76	101.69	17.5	-9	38	73
	3	S.M.C	0.28	107	0.99	101.69	19	-9	34	73
	Whole house			380.5	1.94	101.69	16.2	-9	42.7	73
W.5.2	1	B.U.C		129	2.43	102.04	13	-2	42	73
	2	M.Dr.C		145	1.19	102.04	20.5	-2	28	73
	3	S.M.C		107	0.81	102.04	22	-2	24	73
	Whole house			380.5	1.51	102.04	18.5	-2	31.3	73
W.5.3	1	B.U.C		129	1.85	102.04	12	-2	36	86
	2	M.Dr.C		144	1.03	102.04	19.3	-2	26	86
	3	S.M.C		106	0.52	102.04	20	-2	24	86
	Whole house			380	1.16	102.04	17.1	-2	28.7	86
W.5.4	1	B.U.C		129	0.98	102.74	13.5	9	47	61
	2	M.Dr.C		144	0.7	102.74	21	9	30	61
	3	S.M.C		106	0.36	102.74	22.5	9	28	61
	Whole house			380	0.7	102.74	19	9	35	61
W.5.5	1	B.U.C		129	1	102.5	11	9	45	76
	2	M.Dr.C		144	0.12	102.5	17	9	32	76
	3	S.M.C		106	0.09	102.5	19.5	9	28	76
	Whole house			380	0.41	102.5	15.8	9	35	76

*House W.4 is a slab on grade.

Column C codes

FLOOR LOCATION	ROOM LOCATION	ORIENTATION
B basement	Fr family room	N north
M main floor	Dr dining room	S south
S second floor	Kit kitchen	E east
	Bd bedroom	W west
	Lr living room	NE & etc
	U utility	C central
	H hallway	

MOISTURE SOURCE STRENGTH SUMMARY SHEET. DATE: *********

E	AIR CHANGE (L/s)	HUMIDTY RATIOS INDOOR AHI	OUTDOOR AHO	MOISTURE STRENGTH(kg/day) INTERNAL IMSS	TOTAL TMSS	E	INTERMEDIATE CALCULATIONS SPECIFIC VOLUMES INDOOR(SVi) (m3/kg dry air)	OUTDOOR(SVo) (m3/kg dry air)
	19.3	0.01009	0.00410	11.29	19.03		0.881837	0.811209
D	18.2	0.00660	0.00410	4.52	11.95	D	0.865409	0.811209
	63.3	0.00960	0.00410	33.97	59.31		0.884430	0.811209
	100.8	0.00866	0.00410	45.28	86.00		0.877171	0.811209
O	7.2	0.00835	0.00319	3.69	5.97	O	0.866738	0.783949
	10.9	0.00910	0.00319	6.44	9.91		0.863078	0.783949
F	18.4	0.00884	0.00319	10.39	16.25	F	0.865069	0.783949
	36.4	0.00879	0.00319	20.53	32.21		0.864996	0.783949
	12.1	0.00699	0.00607	1.13	8.54		0.853487	0.813487
U	14.3	0.00625	0.00607	0.26	9.09	O	0.849271	0.813487
	7.3	0.00571	0.00607	-0.27	4.30		0.840690	0.813487
S	33.7	0.00632	0.00607	0.86	21.72	U	0.847908	0.813487
	6.2	0.00800	0.00498	1.91	5.06		0.846964	0.803934
E	5.4	0.00912	0.00498	2.27	5.01	T	0.848475	0.803934
	11.9	0.00817	0.00498	3.87	9.90		0.845446	0.803934
R	23.7	0.00843	0.00498	8.34	20.38	P	0.846953	0.803934
	38.3	0.00696	0.00712	-0.64	28.16		0.828615	0.811102
	33.5	0.00625	0.00712	-3.03	21.98	U	0.822550	0.811102
I	22.9	0.00635	0.00712	-1.88	15.50		0.811537	0.811102
	94.4	0.00655	0.00712	-5.66	65.35	T	0.817511	0.811102
N	97.2	0.00723	0.00693	2.74	66.12		0.823835	0.820299
	33.5	0.00718	0.00693	0.87	25.16	S	0.825482	0.820299
P	36.7	0.00768	0.00693	2.88	29.76		0.818121	0.820299
	157.3	0.00742	0.00693	8.14	123.25		0.822654	0.820299
U	39.7	0.00802	0.00406	16.50	33.42		0.824430	0.806831
	30.0	0.00621	0.00406	6.86	19.86		0.809596	0.806831
T	20.3	0.00772	0.00406	7.85	16.57		0.817784	0.806831
	98.0	0.00728	0.00406	30.75	69.55		0.817221	0.806831
S	100.4	0.00963	0.00394	59.46	100.61		0.830565	0.821387
	30.7	0.00852	0.00394	14.63	27.23		0.829097	0.821387
	23.6	0.00879	0.00394	12.03	21.79		0.822930	0.821387
	154.7	0.00904	0.00394	81.94	145.26		0.827795	0.821387
	238.5	0.00860	0.00516	85.76	214.13		0.827503	0.819876
	127.6	0.00713	0.00516	26.34	95.19		0.825571	0.819876
	6.6	0.00794	0.00516	1.91	5.45		0.825219	0.819876
	372.6	0.00787	0.00516	106.06	307.55		0.825977	0.819876
	5.2	0.00601	0.00394	1.08	3.15		0.849631	0.806394
	4.8	0.00625	0.00394	1.14	3.08		0.847350	0.806394
	5.2	0.00661	0.00394	1.41	3.48		0.846387	0.806394
	15.1	0.00629	0.00394	3.70	9.92		0.847693	0.806394
	5.3	0.00787	0.00501	1.56	4.29		0.840408	0.812543
	0.0	0.00908	0.00501	0.00	0.00		0.873297	0.812543
	4.1	0.00908	0.00501	1.65	3.67		0.873297	0.812543
	9.4	0.00915	0.00501	4.22	9.33		0.863650	0.812543
	14.0	0.00603	0.00278	4.75	8.83		0.824386	0.778264
	11.1	0.00680	0.00278	4.64	7.85		0.830814	0.778264
	22.8	0.00488	0.00278	5.20	12.09		0.795349	0.778264
	47.9	0.00601	0.00278	16.25	30.22		0.816980	0.778264
	10.3	0.00642	0.00574	0.72	6.75		0.845138	0.815688
	14.4	0.00642	0.00574	1.00	9.44		0.846009	0.815688

12.9	0.00500	0.00574	-1.00	6.77	0.825777	0.815688
37.6	0.00594	0.00574	0.76	23.23	0.838950	0.815688
17.7	0.00660	0.00179	8.77	12.04	0.837865	0.773648
20.6	0.00675	0.00179	10.47	14.25	0.841817	0.773648
26.6	0.00497	0.00179	8.91	13.94	0.819866	0.773648
64.9	0.00607	0.00179	28.79	40.86	0.833119	0.773648
25.5	0.00447	0.00100	9.27	11.94	0.823758	0.742199
18.1	0.00445	0.00100	6.55	8.44	0.824876	0.742199
48.0	0.00666	0.00100	28.62	33.66	0.820101	0.742199
91.5	0.00530	0.00100	41.44	51.07	0.823147	0.742199
5.5	0.00927	0.00889	0.21	5.18	0.847532	0.822705
5.5	0.00890	0.00889	0.01	4.95	0.849889	0.822705
18.4	0.00910	0.00889	0.39	17.06	0.848724	0.822705
29.4	0.00910	0.00889	0.63	27.53	0.848724	0.822705
34.7	0.00764	0.00386	13.44	27.15	0.842718	0.782217
35.8	0.00711	0.00386	11.98	26.21	0.837717	0.782217
55.7	0.00691	0.00386	17.53	39.67	0.839172	0.782217
126.1	0.00722	0.00386	43.58	93.56	0.839871	0.782217
ERR	0.00669	0.00384	ERR	ERR	0.900721	0.832408
ERR	0.00669	0.00384	ERR	ERR	0.900721	0.832408
240.6	0.00669	0.00384	65.73	154.33	0.900721	0.832408
240.6	0.00669	0.00384	65.73	154.33	0.900721	0.832408
17.1	0.01160	0.00469	11.17	18.75	0.914283	0.850021
13.3	0.01221	0.00469	9.39	15.25	0.920128	0.850021
22.8	0.01191	0.00469	15.47	25.52	0.917206	0.850021
30.4	0.01191	0.00469	20.63	34.02	0.917206	0.850021
11.7	0.00820	0.00485	3.74	9.15	0.906569	0.855776
12.5	0.00685	0.00485	2.40	8.21	0.901241	0.855776
36.3	0.00798	0.00485	10.78	27.51	0.908090	0.855776
36.3	0.00764	0.00485	9.66	26.44	0.905143	0.855776
12.6	0.00782	0.00419	4.37	9.41	0.905572	0.841815
11.9	0.00631	0.00419	2.46	7.32	0.886574	0.841815
18.2	0.00708	0.00419	5.06	12.39	0.896230	0.841815
24.5	0.00708	0.00419	7.00	17.16	0.896230	0.841815
13.3	0.00665	0.00531	1.83	9.06	0.844639	0.796352
7.3	0.00822	0.00531	2.17	6.12	0.845014	0.796352
9.7	0.00751	0.00531	2.17	7.42	0.847230	0.796352
39.9	0.00748	0.00531	8.85	30.46	0.845754	0.796352
30.3	0.00748	0.00531	6.73	23.15	0.845754	0.796352
20.6	0.00902	0.00359	10.55	17.51	0.915986	0.833692
13.0	0.00582	0.00359	6.60	11.09	0.915986	0.833692
17.6	0.00947	0.00359	9.78	15.73	0.913226	0.833692
57.4	0.00916	0.00359	30.23	49.66	0.914953	0.833692
51.2	0.00916	0.00359	26.87	44.14	0.914953	0.833692
25.4	0.00767	0.00357	9.93	18.54	0.900898	0.828986
14.2	0.00630	0.00357	3.71	8.55	0.903547	0.828986
25.4	0.00797	0.00357	10.67	19.30	0.907798	0.828986
62.2	0.00731	0.00357	22.19	43.32	0.906842	0.828986
65.1	0.00731	0.00357	23.33	45.54	0.906842	0.828986
20.0	0.00692	0.00265	8.17	13.25	0.902139	0.821306
13.0	0.00634	0.00265	4.61	7.92	0.901303	0.821306
17.0	0.00649	0.00265	6.21	10.50	0.904913	0.821306
52.6	0.00661	0.00265	19.91	33.27	0.902924	0.821306
50.0	0.00661	0.00265	18.71	31.26	0.902924	0.821306
17.8	0.00664	0.00354	5.08	10.88	0.893643	0.822503
10.0	0.00701	0.00354	3.35	6.76	0.892338	0.822503
11.5	0.00625	0.00354	3.01	6.93	0.896458	0.822503
41.5	0.00667	0.00354	12.55	26.72	0.894302	0.822503
38.4	0.00667	0.00354	11.58	24.66	0.894302	0.822503

17.7	0.00551	0.00157	7.09	9.92	0.847158	0.762889
8.0	0.00508	0.00157	2.87	4.15	0.846581	0.762889
0.0	0.00529	0.00157	0.00	0.00	0.846869	0.762889
25.7	0.00529	0.00157	9.93	14.11	0.846869	0.762889
16.2	0.01039	0.00226	13.50	17.25	0.841966	0.761232
20.7	0.00939	0.00226	15.28	20.11	0.835241	0.761232
42.7	0.00991	0.00226	33.70	43.64	0.838771	0.761232
36.9	0.00991	0.00226	28.88	37.41	0.838771	0.761232
38.1	0.00582	0.00184	15.86	23.18	0.826917	0.755986
20.9	0.00544	0.00184	7.82	11.81	0.831236	0.755986
20.9	0.00595	0.00184	8.89	12.86	0.834747	0.755986
41.8	0.00581	0.00184	17.22	25.19	0.831161	0.755986
3.9	0.00860	0.00382	1.93	3.48	0.830058	0.792643
4.6	0.00876	0.00382	2.35	4.18	0.829687	0.792643
3.2	0.00904	0.00382	1.71	2.97	0.831488	0.792643
11.6	0.00878	0.00382	5.96	10.57	0.830284	0.792643
104.3	0.00495	0.00141	39.24	54.93	0.811335	0.747348
70.9	0.00479	0.00141	25.01	35.48	0.826778	0.747348
29.4	0.00471	0.00141	10.08	14.41	0.830938	0.747348
204.6	0.00496	0.00141	76.24	106.64	0.823298	0.747348
87.1	0.00394	0.00240	14.29	36.61	0.810089	0.765737
47.9	0.00424	0.00240	9.14	21.11	0.831716	0.765737
24.1	0.00398	0.00240	3.93	9.92	0.835623	0.765737
159.1	0.00418	0.00240	29.71	69.84	0.825977	0.765737
66.3	0.00316	0.00283	2.31	22.45	0.806248	0.766264
41.2	0.00365	0.00283	3.51	15.70	0.827538	0.766264
15.3	0.00352	0.00283	1.09	5.61	0.829344	0.766264
122.8	0.00351	0.00283	8.68	45.19	0.821125	0.766264
35.1	0.00453	0.00436	0.65	17.04	0.806734	0.793851
28.0	0.00466	0.00436	0.87	13.60	0.828006	0.793851
10.6	0.00476	0.00436	0.45	5.24	0.832373	0.793851
73.7	0.00480	0.00436	3.41	37.24	0.822563	0.793851
35.8	0.00368	0.00545	-6.85	14.24	0.800484	0.797100
4.8	0.00387	0.00545	-0.80	1.96	0.817633	0.797100
2.7	0.00396	0.00545	-0.41	1.10	0.824801	0.797100
43.3	0.00392	0.00545	-7.03	18.01	0.814317	0.797100

INTERMEDIATE CALCULATIONS

INDOOR			OUTDOOR			CONSTANTS					
Ra J/KgK	Pv kPa	Pvs kPa	Ra J/KgK	Pv kPa	Pvs kPa	C8	C9	C10	C11	C12	C13
287.06	1.563	2.841	287.06	0.641	0.705	-5800.22	1.391499	-0.04860	0.000041	-0.00000	6.545967
287.06	1.027	2.233	287.06	0.641	0.705						
287.06	1.488	3.037	287.06	0.641	0.705						
287.06	1.345	2.689	287.06	0.641	0.705						
287.06	1.318	2.928	287.06	0.507	0.507						
287.06	1.435	2.656	287.06	0.507	0.507						
287.06	1.395	2.790	287.06	0.507	0.507						
287.06	1.386	2.790	287.06	0.507	0.507						
287.06	1.106	2.304	287.06	0.961	0.961						
287.06	0.989	2.151	287.06	0.961	0.961						
287.06	0.906	1.812	287.06	0.961	0.961						
287.06	1.000	2.084	287.06	0.961	0.961						
287.06	1.263	1.944	287.06	0.790	0.790						
287.06	1.438	1.944	287.06	0.790	0.790						
287.06	1.291	1.871	287.06	0.790	0.790						
287.06	1.330	1.919	287.06	0.790	0.790						
287.06	1.124	1.561	287.06	1.149	1.305						
287.06	1.011	1.743	287.06	1.149	1.305						
287.06	1.026	1.350	287.06	1.149	1.305						
287.06	1.058	1.540	287.06	1.149	1.305						
287.06	1.168	1.743	287.06	1.120	1.623						
287.06	1.159	1.812	287.06	1.120	1.623						
287.06	1.238	1.510	287.06	1.120	1.623						
287.06	1.198	1.687	287.06	1.120	1.623						
287.06	1.304	2.006	287.06	0.665	1.510						
287.06	1.012	1.510	287.06	0.665	1.510						
287.06	1.255	1.743	287.06	0.665	1.510						
287.06	1.185	1.743	287.06	0.665	1.510						
287.06	1.563	2.233	287.06	0.645	2.151						
287.06	1.385	2.233	287.06	0.645	2.151						
287.06	1.429	1.931	287.06	0.645	2.151						
287.06	1.468	2.137	287.06	0.645	2.151						
287.06	1.398	2.151	287.06	0.843	2.006						
287.06	1.161	2.151	287.06	0.843	2.006						
287.06	1.292	2.084	287.06	0.843	2.006						
287.06	1.281	2.124	287.06	0.843	2.006						
287.06	0.957	2.392	287.06	0.630	0.955						
287.06	0.995	2.262	287.06	0.630	0.955						
287.06	1.052	2.192	287.06	0.630	0.955						
287.06	1.001	2.276	287.06	0.630	0.955						
287.06	1.234	1.452	287.06	0.789	0.830						
287.06	1.420	2.841	287.06	0.789	0.830						
287.06	1.420	2.841	287.06	0.789	0.830						
287.06	1.431	2.319	287.06	0.789	0.830						
287.06	0.978	1.956	287.06	0.454	0.720						
287.06	1.103	2.206	287.06	0.454	0.720						
287.06	0.793	1.030	287.06	0.454	0.720						
287.06	0.976	1.655	287.06	0.454	0.720						
287.06	1.017	1.956	287.06	0.910	1.023						
287.06	1.017	1.994	287.06	0.910	1.023						

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287.06	0.941	1.732	287.06	0.910	1.023
287.06	1.057	2.032	287.06	0.289	0.507
287.06	1.081	2.206	287.06	0.289	0.507
287.06	0.797	1.423	287.06	0.289	0.507
287.06	0.972	1.859	287.06	0.289	0.507
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287.06	0.725	2.071	287.06	0.163	0.292
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287.06	0.861	1.944	287.06	0.163	0.292
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287.06	1.436	3.055	287.06	1.434	1.687
287.06	1.467	2.964	287.06	1.434	1.687
287.06	1.467	2.964	287.06	1.434	1.687
287.06	1.233	2.624	287.06	0.626	0.720
287.06	1.148	2.392	287.06	0.626	0.720
287.06	1.117	2.483	287.06	0.626	0.720
287.06	1.167	2.498	287.06	0.626	0.720
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287.06	1.005	2.392	287.06	0.579	0.579
287.06	1.005	2.392	287.06	0.579	0.579
287.06	1.005	2.392	287.06	0.579	0.579
287.06	1.727	2.656	287.06	0.706	0.830
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287.06	1.771	2.790	287.06	0.706	0.830
287.06	1.229	2.560	287.06	0.730	0.961
287.06	1.029	2.392	287.06	0.730	0.961
287.06	1.195	2.656	287.06	0.730	0.961
287.06	1.146	2.529	287.06	0.730	0.961
287.06	1.178	2.739	287.06	0.634	0.773
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287.06	1.067	2.319	287.06	0.634	0.773
287.06	1.068	2.483	287.06	0.854	0.854
287.06	1.316	2.392	287.06	0.854	0.854
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287.06	1.199	2.483	287.06	0.854	0.854
287.06	1.342	2.733	287.06	0.538	0.538
287.06	1.342	2.739	287.06	0.538	0.538
287.06	1.408	2.560	287.06	0.538	0.538
287.06	1.363	2.673	287.06	0.538	0.538
287.06	1.363	2.673	287.06	0.538	0.538
287.06	1.156	2.739	287.06	0.538	0.538
287.06	0.947	2.560	287.06	0.538	0.538
287.06	1.195	2.656	287.06	0.538	0.538
287.06	1.097	2.656	287.06	0.538	0.538
287.06	1.097	2.656	287.06	0.538	0.538
287.06	1.032	2.151	287.06	0.398	0.398
287.06	0.946	2.151	287.06	0.398	0.398
287.06	0.968	2.304	287.06	0.398	0.398
287.06	0.986	2.206	287.06	0.398	0.398
287.06	0.986	2.206	287.06	0.398	0.398
287.06	1.005	2.392	287.06	0.538	0.538
287.06	1.060	2.304	287.06	0.538	0.538
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287.06	1.010	2.422	287.06	0.538	0.538
287.06	1.010	2.422	287.06	0.538	0.538

287.06	0.876	2.247	287.06	0.251	0.331
287.06	0.809	2.247	287.06	0.251	0.331
287.06	0.843	2.247	287.06	0.251	0.331
287.06	0.843	2.247	287.06	0.251	0.331
287.06	1.686	2.858	287.06	0.371	0.538
287.06	1.527	2.545	287.06	0.371	0.538
287.06	1.610	2.706	287.06	0.371	0.538
287.06	1.610	2.706	287.06	0.371	0.538
287.06	0.946	2.151	287.06	0.301	0.430
287.06	0.885	2.392	287.06	0.301	0.430
287.06	0.967	2.545	287.06	0.301	0.430
287.06	0.945	2.362	287.06	0.301	0.430
287.06	1.393	2.111	287.06	0.624	1.023
287.06	1.417	2.084	287.06	0.624	1.023
287.06	1.463	2.151	287.06	0.624	1.023
287.06	1.420	2.111	287.06	0.624	1.023
287.06	0.802	1.433	287.06	0.230	0.316
287.06	0.777	2.045	287.06	0.230	0.316
287.06	0.764	2.247	287.06	0.230	0.316
287.06	0.804	1.883	287.06	0.230	0.316
287.06	0.643	1.530	287.06	0.393	0.538
287.06	0.691	2.467	287.06	0.393	0.538
287.06	0.649	2.706	287.06	0.393	0.538
287.06	0.682	2.178	287.06	0.393	0.538
287.06	0.516	1.433	287.06	0.463	0.538
287.06	0.595	2.290	287.06	0.463	0.538
287.06	0.574	2.392	287.06	0.463	0.538
287.06	0.572	1.994	287.06	0.463	0.538
287.06	0.743	1.581	287.06	0.715	1.172
287.06	0.763	2.545	287.06	0.715	1.172
287.06	0.781	2.790	287.06	0.715	1.172
287.06	0.787	2.247	287.06	0.715	1.172
287.06	0.603	1.341	287.06	0.891	1.172
287.06	0.634	1.981	287.06	0.891	1.172
287.06	0.649	2.319	287.06	0.891	1.172
287.06	0.642	1.835	287.06	0.891	1.172

APPENDIX 2

PROCEDURES USED

Recommended Test Procedures For

INTERNAL MOISTURE SOURCE STRENGTH

INTRODUCTION

This test is designed to be used, in conjunction with an Air Change Rate Test, to determine the quantity of water vapour being introduced, into an enclosed space, by internal sources. It can also be used to determine the internal rate of production of other contaminants, through use of the appropriate sensors. If outdoor moisture (contaminant) levels are not measured, it can be used to determine a total apparent source strength that is dependent on ventilation rate, if any moisture (contaminant) exists in the outdoors air.

EQUIPMENT

1) 1 Cylinder of SF6 (sulphur hexafluoride)
2) 2 60cc syringes and needles. One syringe is used solely for injecting the SF6 into the indoor air while the other is used solely for taking the samples.
3) 1 20 ml Vacutainer for each sample to be taken
4) Differential Pressure, (i.e. incline manometer).
5) Wind Speed & Direction, (i.e. cup anemometer).
6) Relative Humidity & Temperature, (i.e. sling psychrometer).
7) Barometric Pressure, (i.e. from local airport).
8) Pen and Paper.

This equipment may be obtained from a medical supply store and an industrial & scientific store. The SF6 may be obtained from a chemical and gas supplier.

HOUSE CONDITIONS

Do not significantly modify the normal ventilation conditions of the test unit before or during the air change rate/moisture source strength test.

Open all interior doors so that the tracer gas may be distributed throughout the house under test.

Close all windows and the fireplace damper, should there be one.

If the house has a forced air heating system, turn the thermostat to its lowest setting to shut off the burner, and turn the fan on, so as to provide a distribution of the tracer gas throughout the house. If a fresh air makeup is present, either block off this duct or leave the furnace fan off for the duration of the test. This fan is usually controlled by a switch near or in the furnace housing.

PROCEDURE

1. Leave tracer gas container outside house so as not to risk additional gas leakage.

2. Arrange furnace controls as mentioned above.

3. Calculate interior volume of the house, in m3, including basement.

4. Calculate volume of SF6, such that initial concentration in house will be appoximately 50 ppb:
   Vsf6 = 0.05 V of house, with Vsf6 in cc and V of house in m3.

5. Measure and record the outdoor relative humidity and the dry bulb temperature, on the windward side on the unit.

6. Transfer SF6 to syringe as follows:

   1. Transfer gas to syringe outside house (e.g., in vehicle).
   2. Turn valve connected to regulator outlet off.
   3. Turn regulator valve out, so that it will transfer zero pressure to the output.
   4. To reduce loss of SF6 due to leakage, open lecture bottle valve (regulator input, i.e. high pressure, gauge will indicate bottle pressure), then shut it off.
   5. Turn regulator valve in unit regulator output (low pressure) gauge reads approximately 20 psi.
   6. Using a syringe (reserved for pure SF6, to ensure samples are not contaminated) push the plunger all the way in.
   7. Insert needle through septum.
   8. Slightly open valve connected to regulator outlet and pressure will push syringe plunger out. Close valve when desired quantity of SF6 is in syringe.
   9. Remove syringe and cap needle with rubber bung.
   10. Turn valve connected to regulator outlet off, and turn regulator valve out.

7. Inject SF6 into house as follows:

   1. Take syringe immediately to basement, remove bung and insert needle into duct through access hole (i.e. remove duct screw) and slowly push the syringe plunger in fully, repeat this to ensure SF6 is flushed from syringe. Inject directly into the return air supply at the furnace or at the start of the distribution vent on the furnace. If there is no forced air distribution system you must manually distribute proportionaly the SF6 throughtout the house by injecting the gas into each room and then using a piece of cardboard, fan the SF6 around the room.
   2. Record the time of injection.

8. Measure and record the average indoor relative humidity and dry bulb temperature.

9. Sampling Procedure

1. Five samples from each level and five samples from the return air at the furnace should be sampled.
2. Prepare a list of all the vacutainers you will require for sampling and record the location where the sample will be taken from, on the vacutainer and in a separate book.
3. After injecting the SF6 into the furnace or having distributed the SF6 manually, wait for a minimum of 30 minutes before taking the first sample. Take subsequent samples every 15 minutes until the five samples have been obtained from each level and the return air (if applicable).
4. The samples are taken as follows:
   Take the sampling syringe for the area you are sampling and flush it in and out twice before sampling. Then slowly draw in 50cc of air from the return air duct and/or from the floor area. Then push the plunger in 10cc to a reading of 40cc before inserting the syringe needle into the vacutainer and allowing the vacutainer to draw the air from the syringe until it stops. Then proceed to push the plunger until you have inserted 25cc or the reading on the syringe is 15cc.

10. Record the time of each sample to the closest minute.

11. Measure and record the indoor relative humidity and dry bulb temperature, within 1 minute of each tracer gas sample, consistently before or after that sampling operation. Alternately, measure wet and dry bulb temperatures only.

12. Proceed from floor to floor starting with the first sample being taken from the return air.

13. Measure and record the outdoor relative humidity and dry bulb temperature, following the last tracer gas sampling operation.

14. Measure and record the outside barometric pressure, plus wind velocity and direction.

15. Measure and record the pressure difference (in Pa) between the centre of the upwind wall and a point 1m above the basement floor. A positive pressure difference indicates a higher internal pressure.

16. Completion:

1. Replace screw in return air duct or seal hole.
2. Return fan switch to original setting & reset thermostat.

17. Have vacutainer contents analyzed for concentration of SF6 within 1 week of sampling.

ANALYSIS

The samples should be packaged to avoid breakage during transit and sent by courier to the following for analysis:

Mr. W.M. Neaves
Enviroclean
320 Adelaide Street South
London, Ontario
N5Z 3L2
(519) 686-7558

Upon receipt of the concentrations of SF6 the air change rate per unit time can then be calculated using the following equation:

$$I(i) = \ln(C(i)/C(i-1)) / (t(i-1) - t(i))$$

where $I(i)$ = air change rate at time i

$C(i)$ = concentration of SF6 at time i

$C(i-1)$ = concentration of SF6 at time $i-1$

i = time interval

The above equation establishes air change values between each time interval.

These values are then either plotted graphically or run through a least squares analysis to determine the best fit exponential curve, the slope and the correlation.

Moisture Analysis:

1. Average the outdoor relative humidity and dry bulb temperature, plus the indoor relative humidity and dry bulb temperature, and record as RHO, OAT, RHI and IAT, respectively.

2. Determine the air change rate, according to the appropriate procedure, in m3/s (m3/s=lps/1000).

3. Correct the air change rate to average indoor conditions, if necessary, using Boyles Law, and record as ACR.

4. Using the Psychrometric Chart, or Boyles Law, determine the Specific Volume of the indoor dry air and record as SV (Specific Volume is the inverse of density and is expressed in m3/kg).

5. Using the Psychrometric Chart, or the equations in AHRAE "Fundamentals", Chapter 5 "Psychrometrics", determine the indoor and outdoor absolute humidity ratios, in Kg Water Vapour per Kg Dry Air, and record as AHO and AHI, respectively.

6. Calculate the apparent internal moisture source strength (IMSS), in kg/day or litres/day, from:

$$IMSS = 86{,}400 \frac{ACR}{SV} (AHI - AHO)$$

The total moisture source strength (TMSS), including moisture brought in with the ventilating air, can be calculated from:

$$TMSS = 86{,}400 \frac{ACR}{SV} (AHI)$$

7. Report the following:

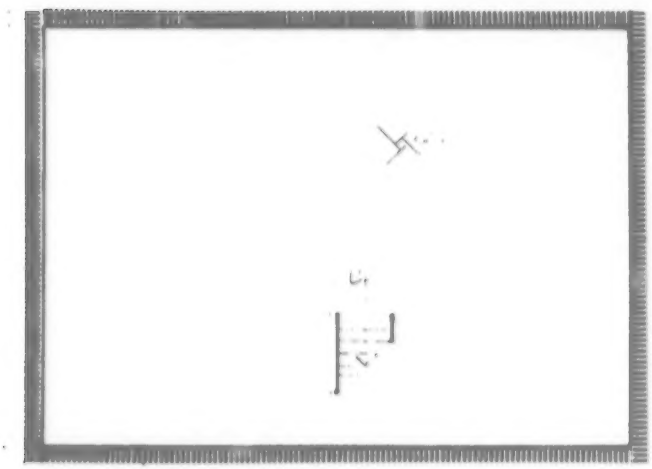
Date of test.
House location and/or identifier.
Orientation (degrees).
House type and construction date.
House useful floor area (m2).
Additional basement floor area (if appropriate) (m2).
House internal air volume (m3).
Barometric Pressure (KPa).
Wind Velocity and direction (kph, degrees).
Basement pressure difference (Pa).

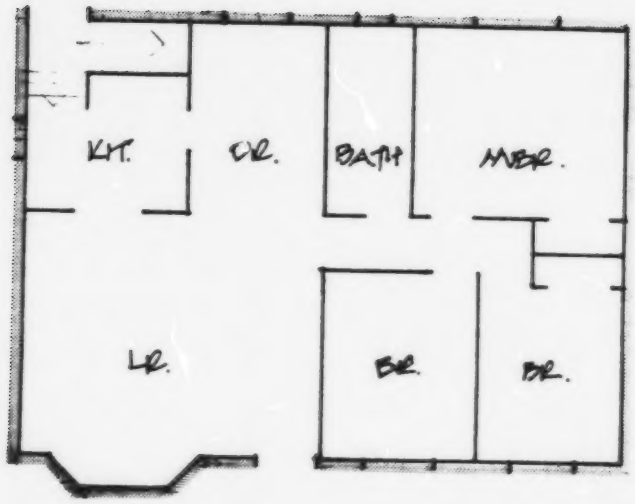
Average outside air temperature - OAT (degrees C).
Average outside relative humidity - RHO (%).
Average inside air temperature - IAT (degrees C).
Average inside relative humidity - RHI (%).
Air change rate - ACR (m3/s).
Apparent internal moisture source strength - IMSS (kg/day).
Apparent total moisture source strength - TMSS (kg/day).

APPENDIX 3

HOUSE FLOOR PLANS

DR.
KIT.
BR.
BR.
LR.
BATH
BR.

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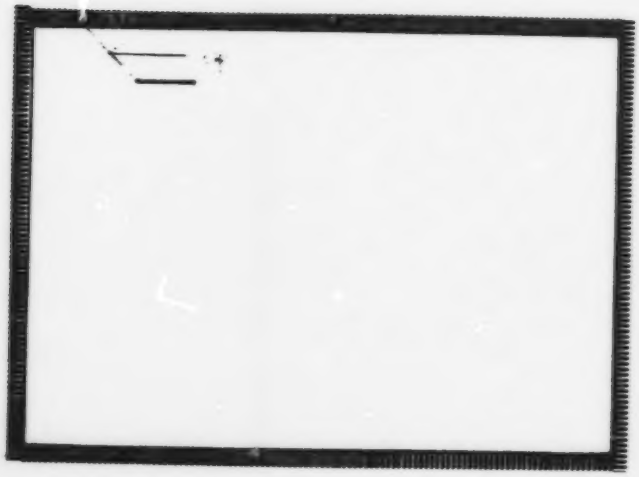

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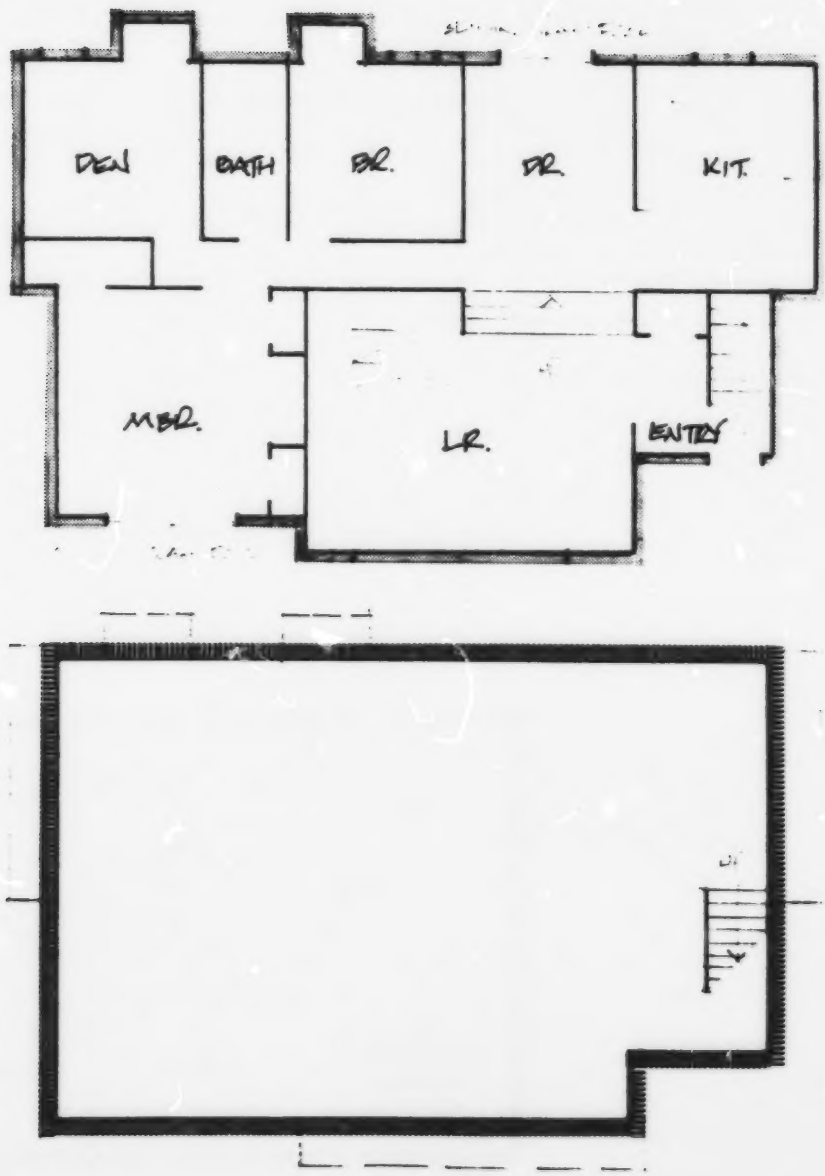

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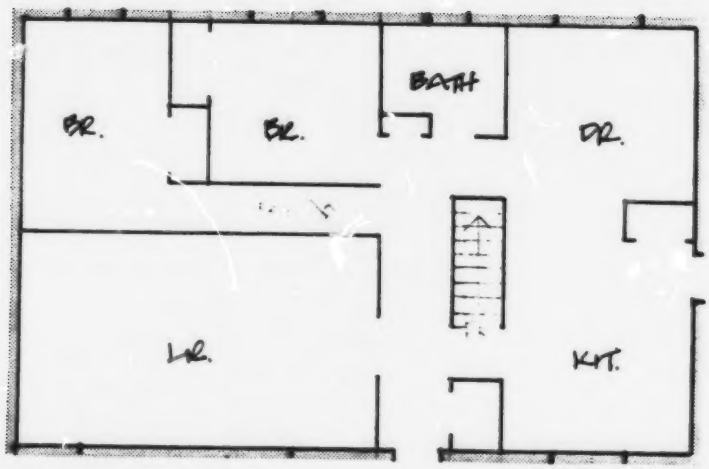
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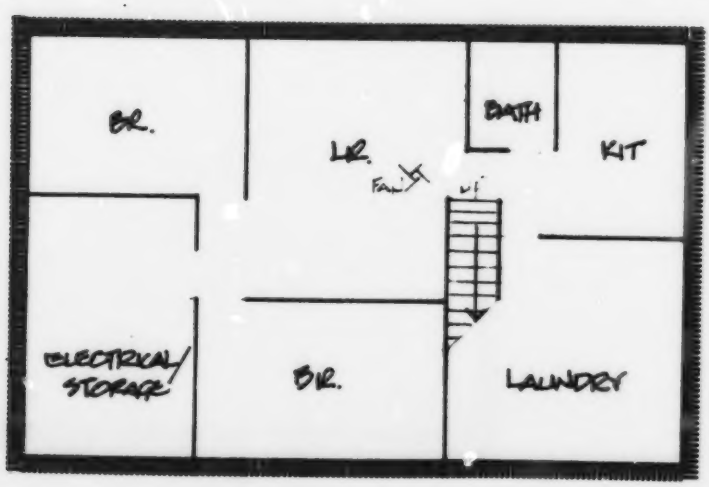
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ELECTRICAL/ STORAGE
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LAUNDRY

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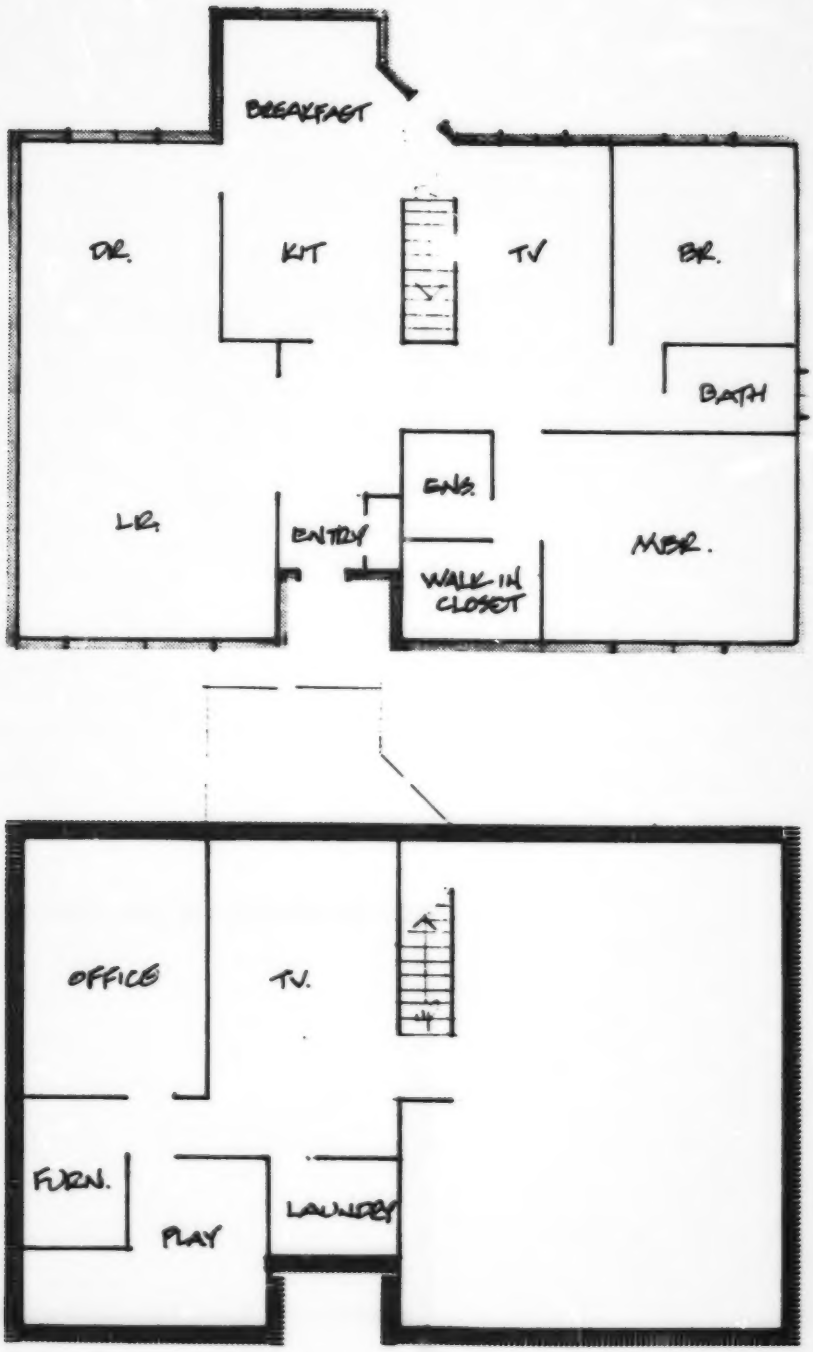
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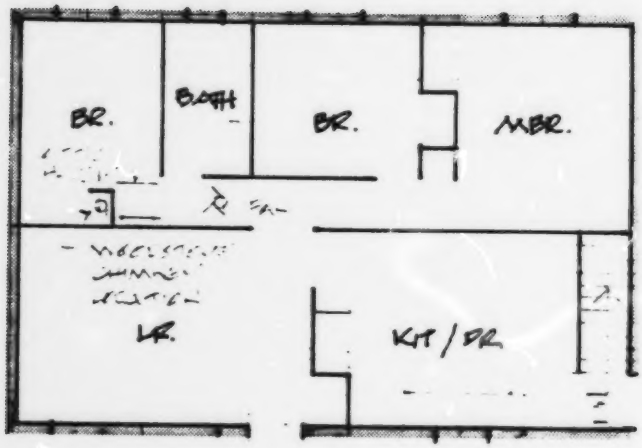
FURN.
PLAY
LAUNDRY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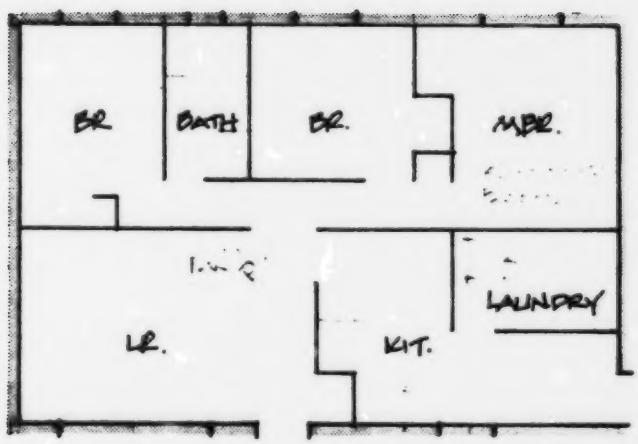
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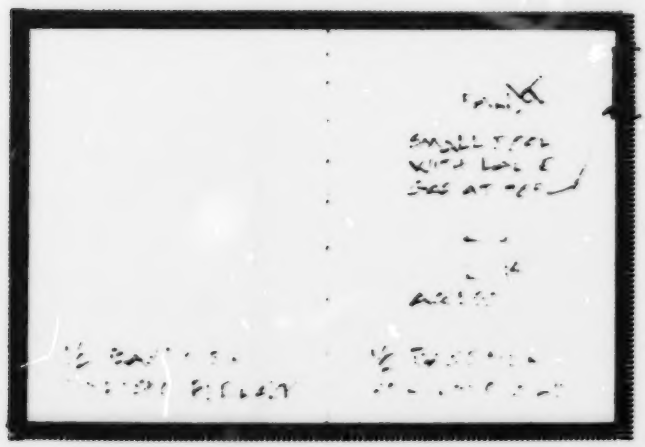

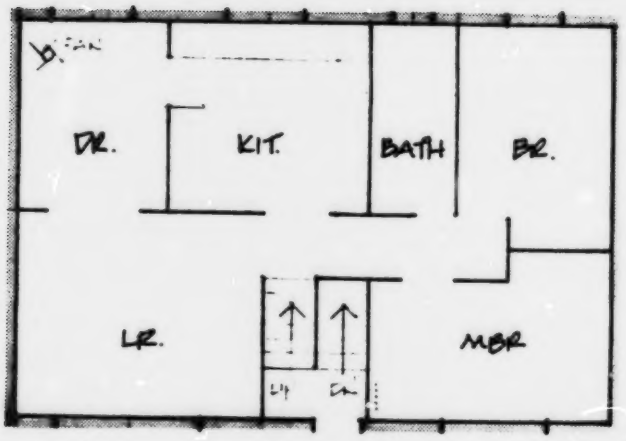
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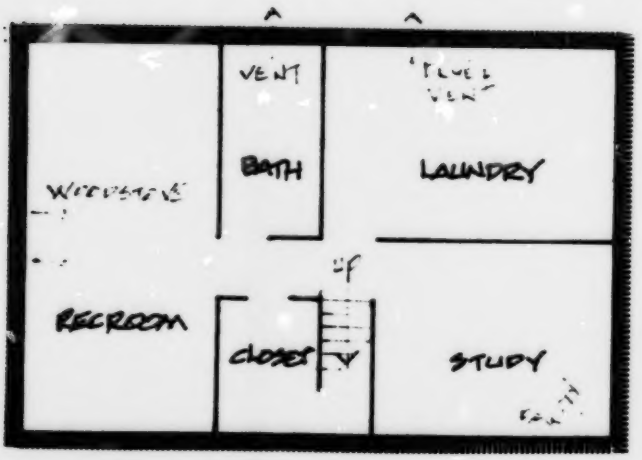
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LAUNDRY
RECROOM
CLOSET
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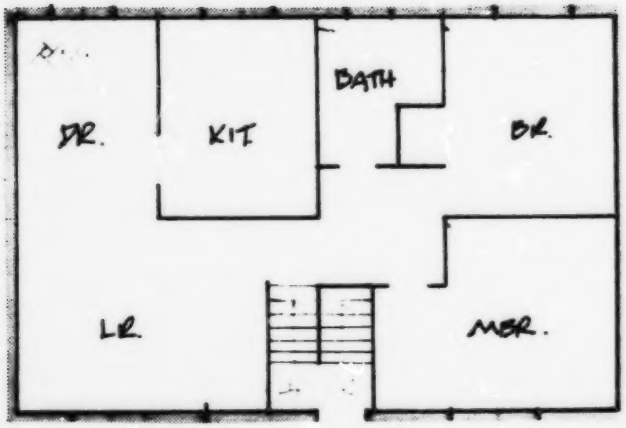
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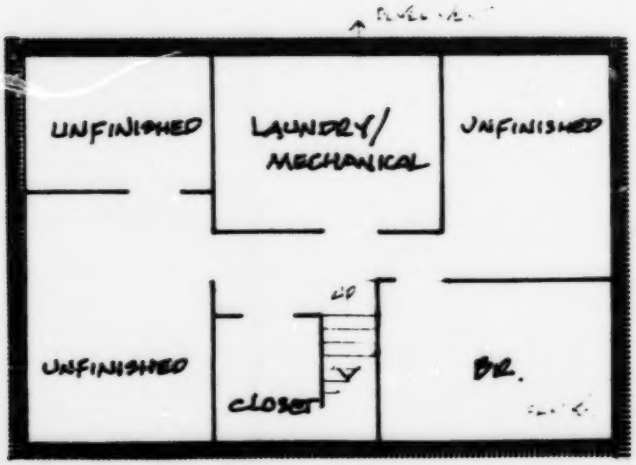
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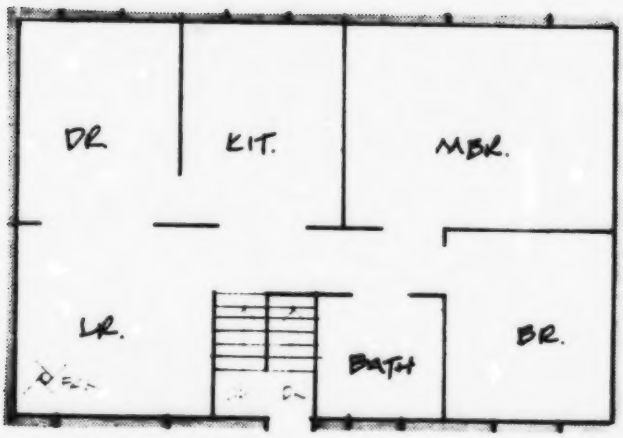
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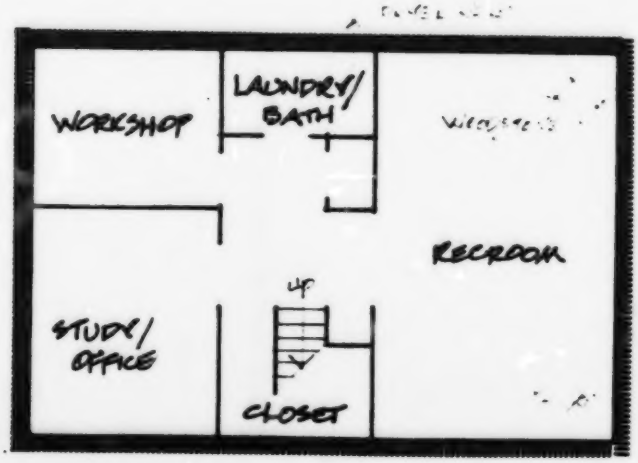
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BATH
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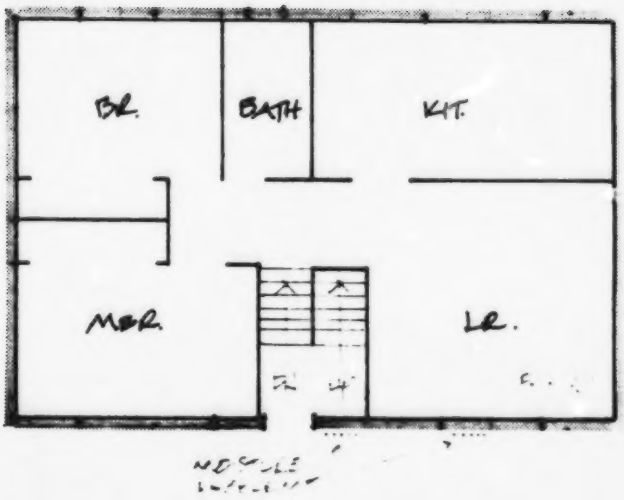
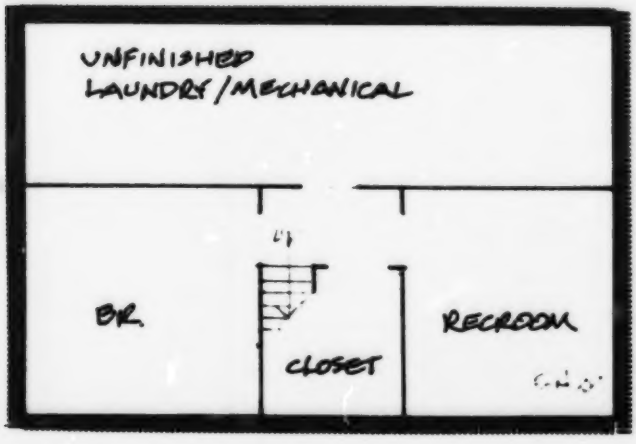
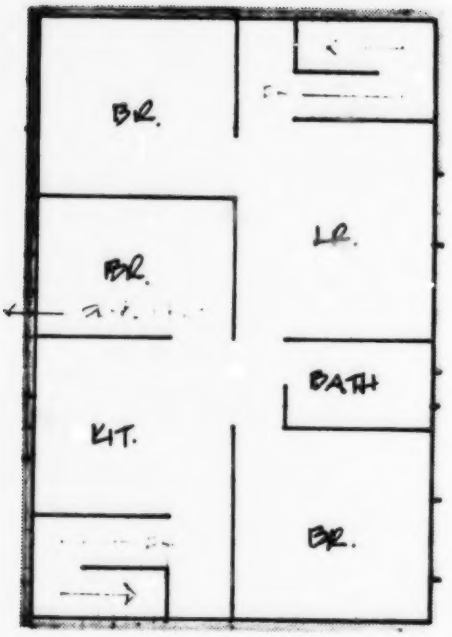
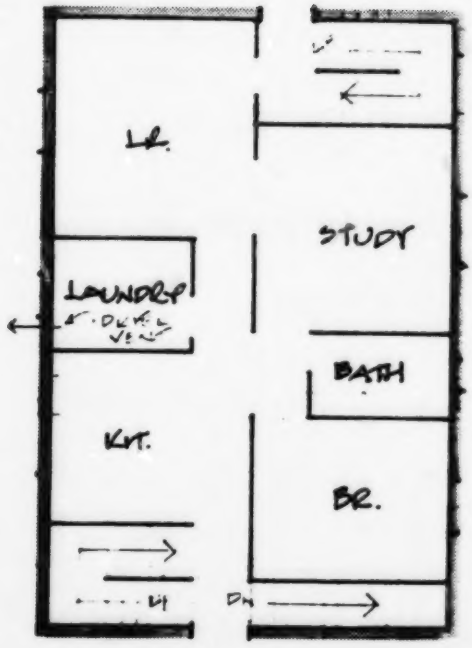
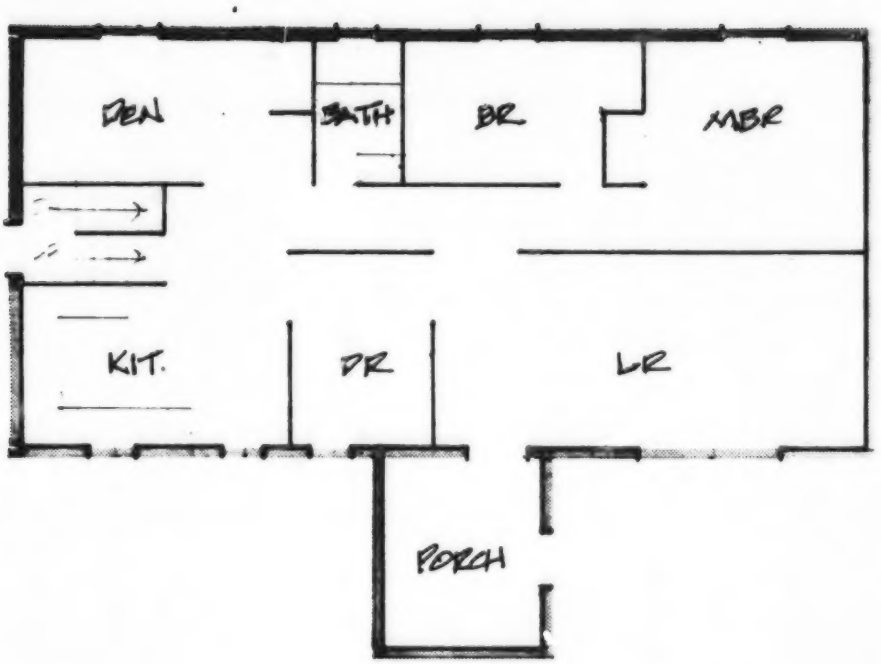
UP
STUDY/
OFFICE
CLOSET

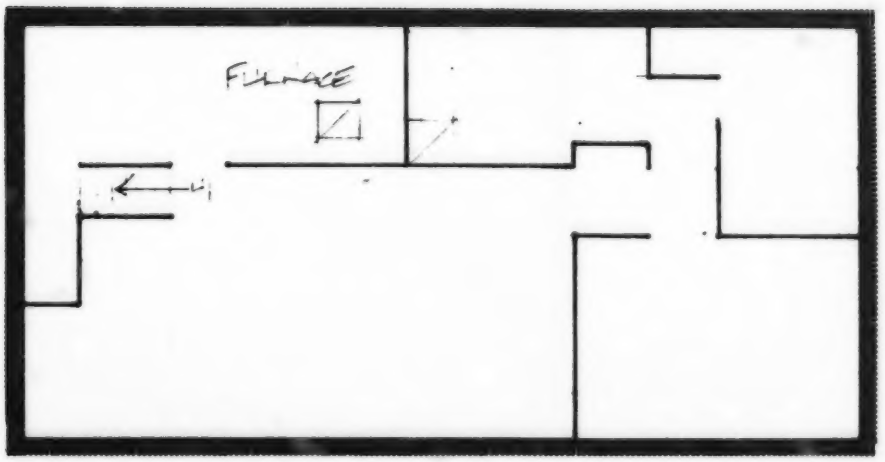

BR.
BATH
KIT.
MBR.
LR.

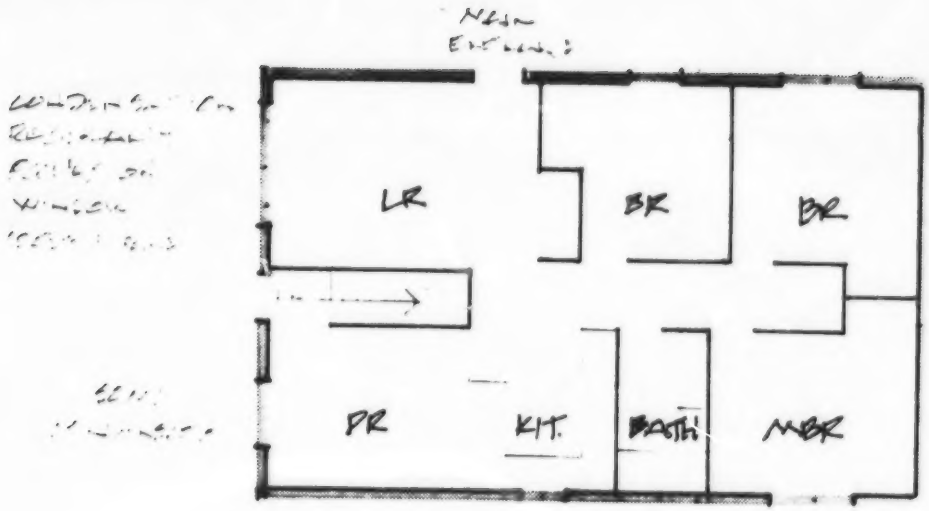

UNFINISHED
LAUNDRY/MECHANICAL
BR.
CLOSET
RECROOM

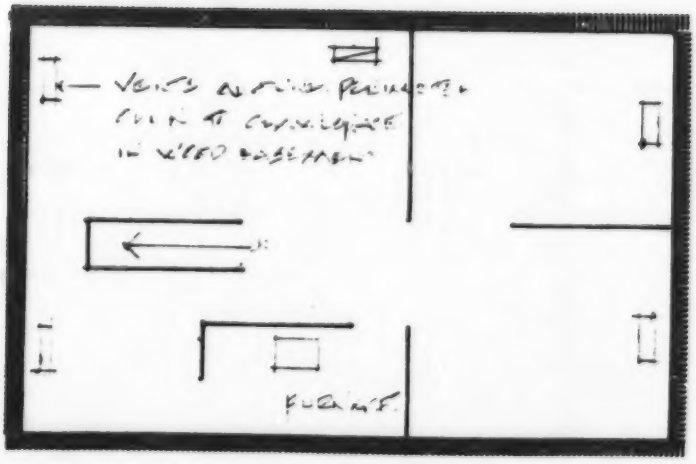

BR.
LR.
BR.
BATH
KIT.
BR.

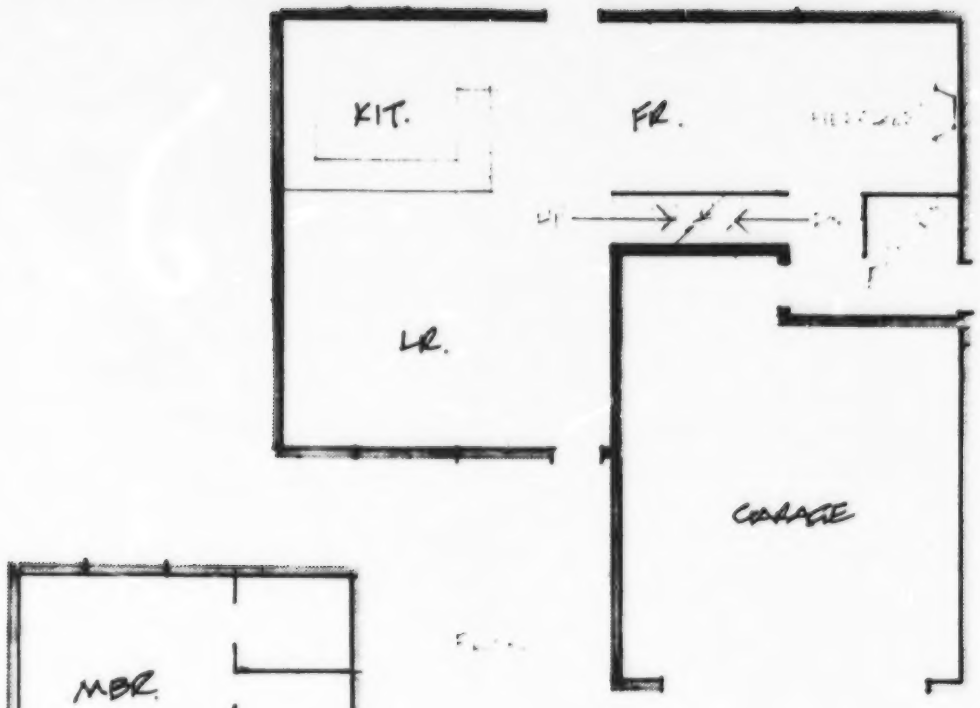

LR.
STUDY
LAUNDRY
BATH
KIT.
BR.

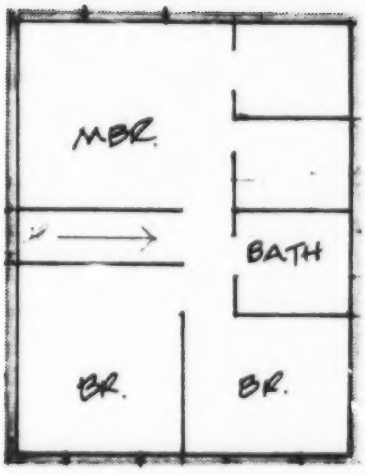

DEN
BATH
BR
MBR
KIT.
DR
LR
PORCH


FURNACE


LR
BR
BR
DR
KIT.
BATH
MBR




KIT.
FR.
LR.
GARAGE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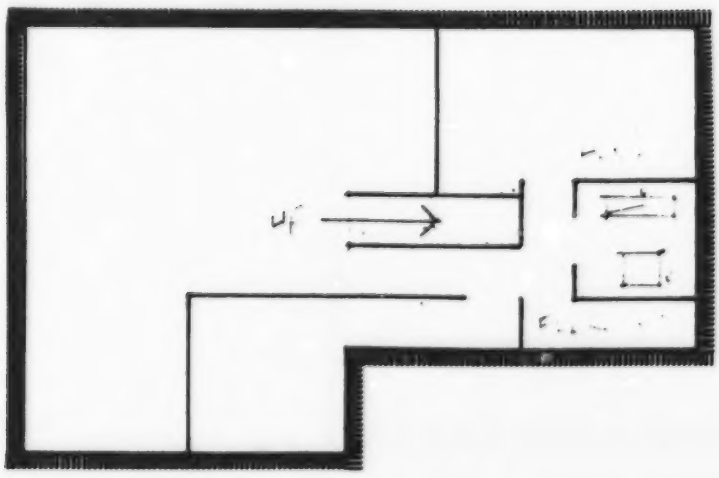
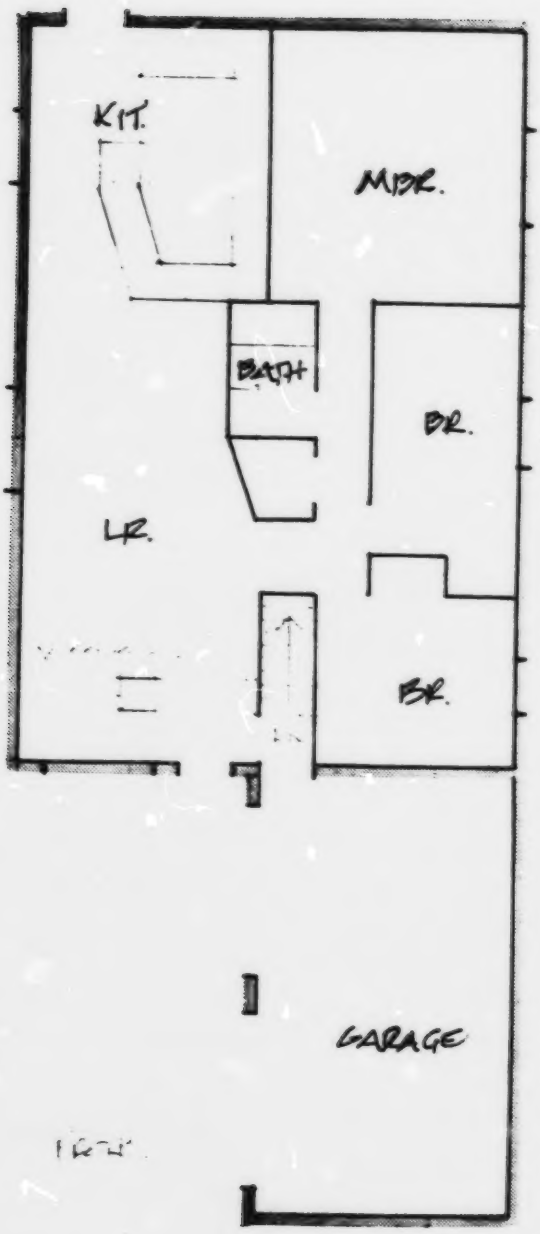
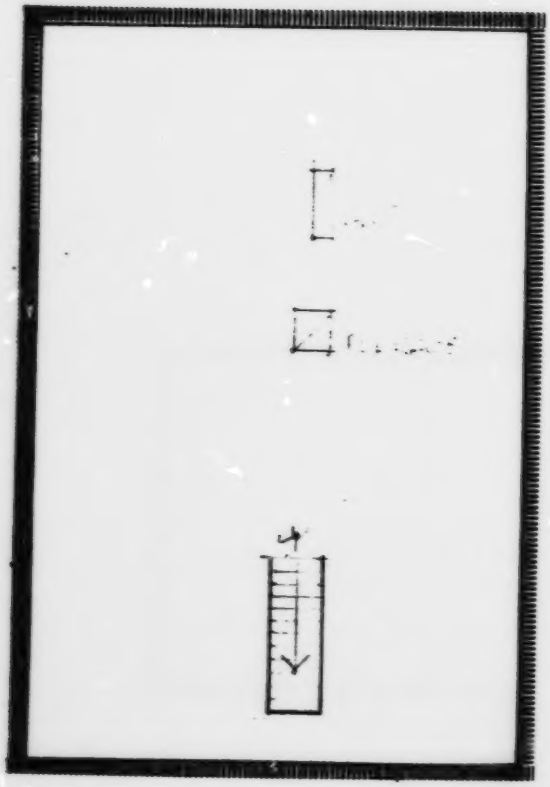
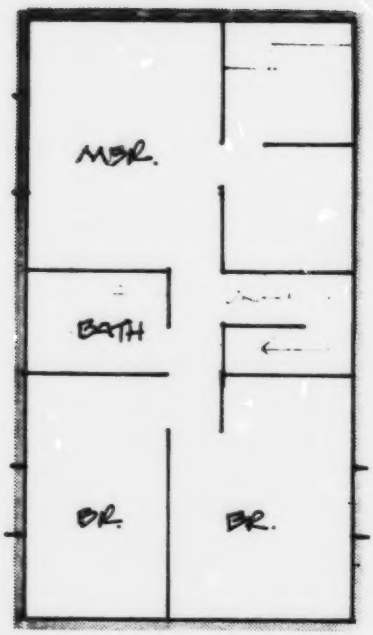
BATH
BR.
BR.




KIT.
MBR.
BATH
BR.
LR.
BR.
GARAGE

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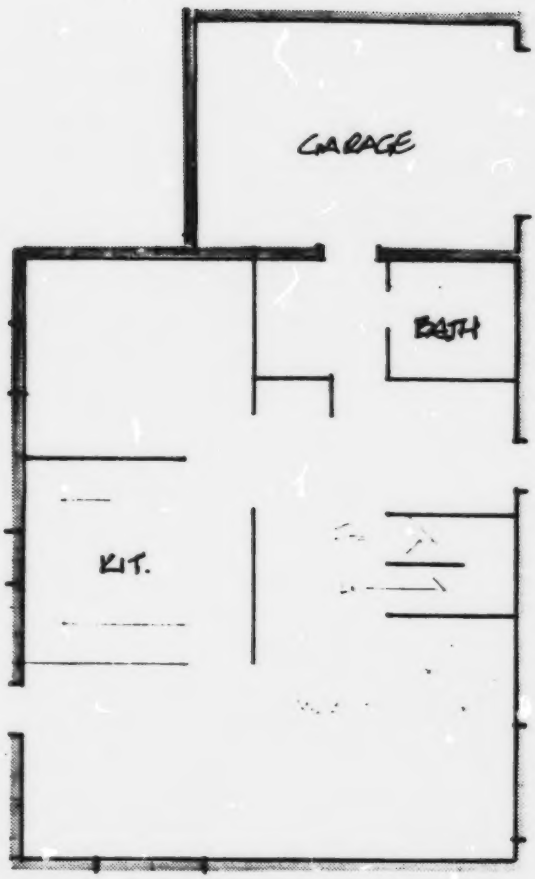
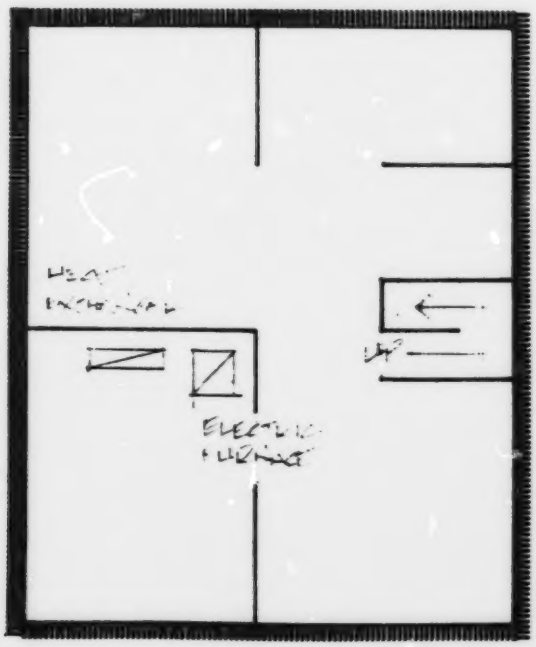
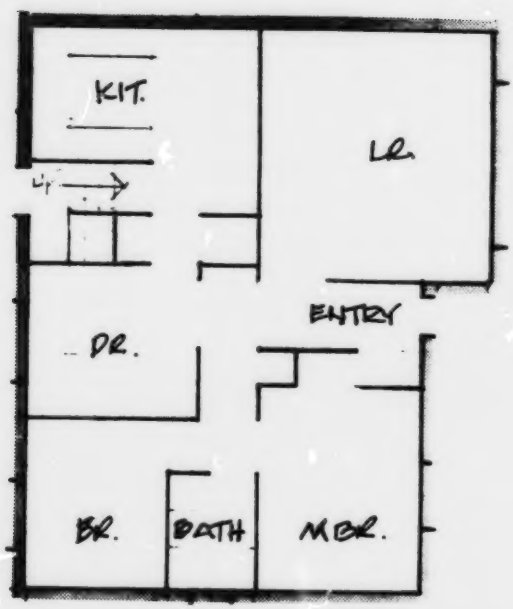
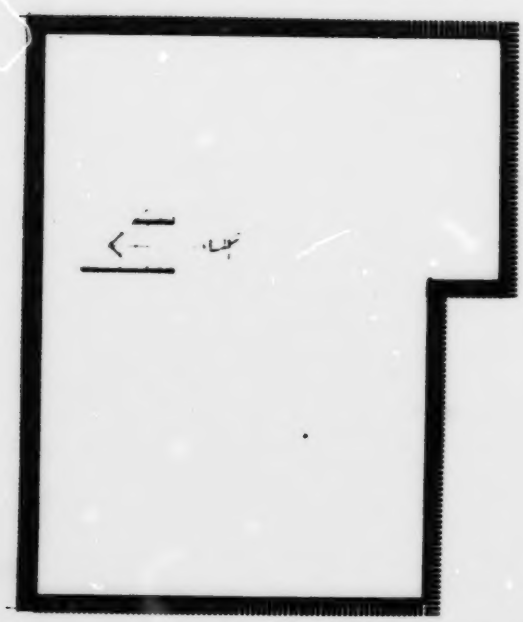
BATH
BR.
BR.

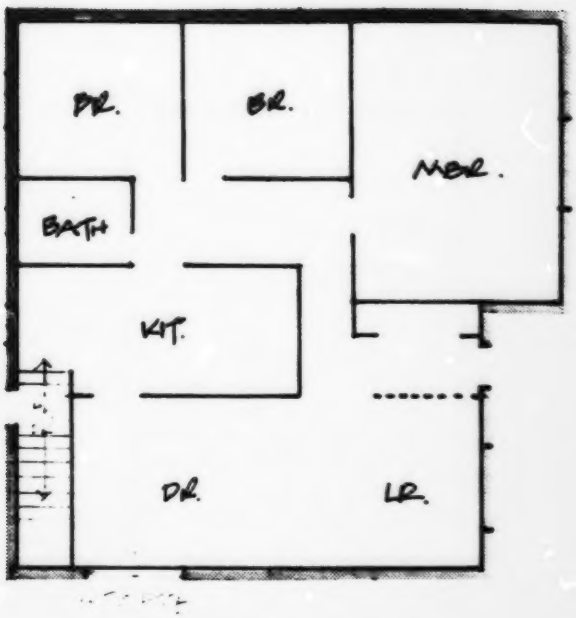

GARAGE
BATH
KIT.

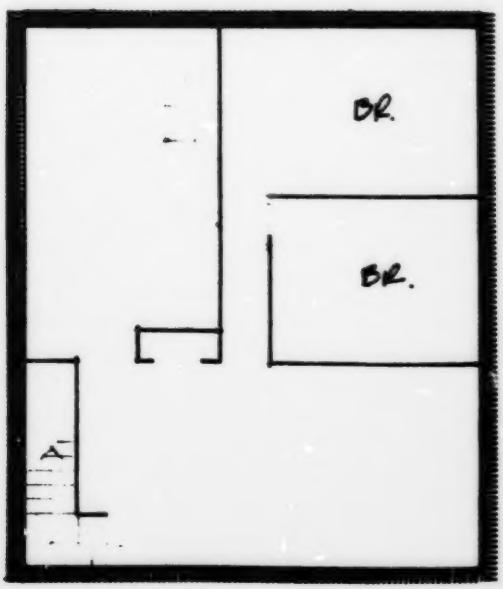

HEAT
ELECTRIC
HEATING

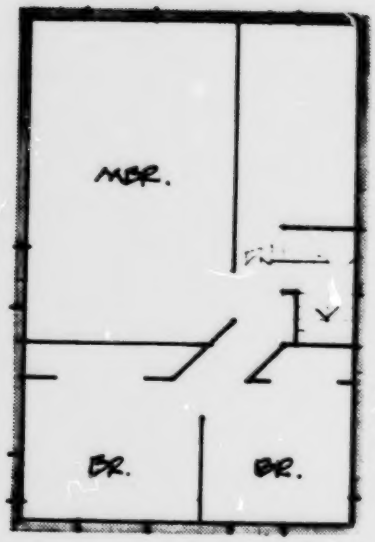

KIT.
LR.
ENTRY
DR.
BR.
BATH
MBR.

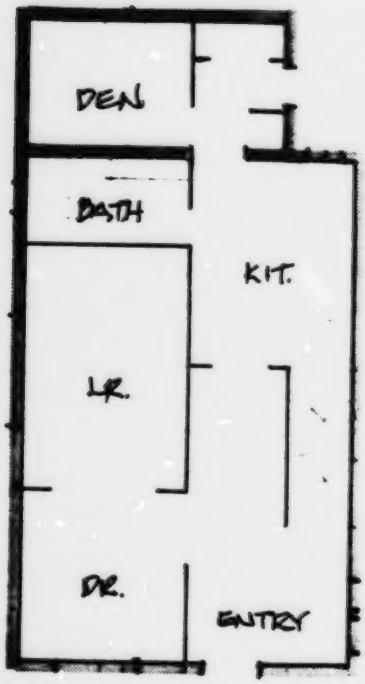


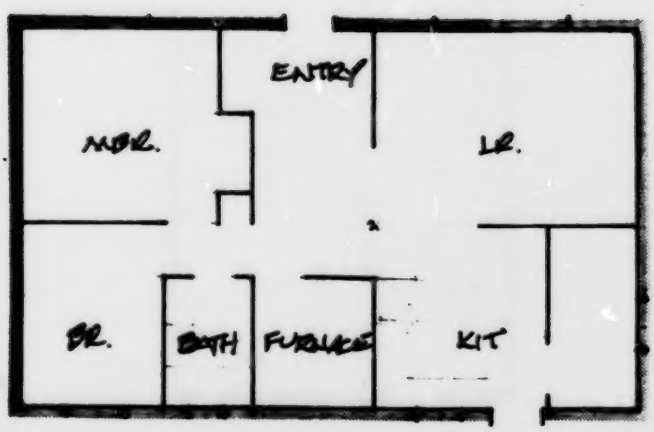
VI.C



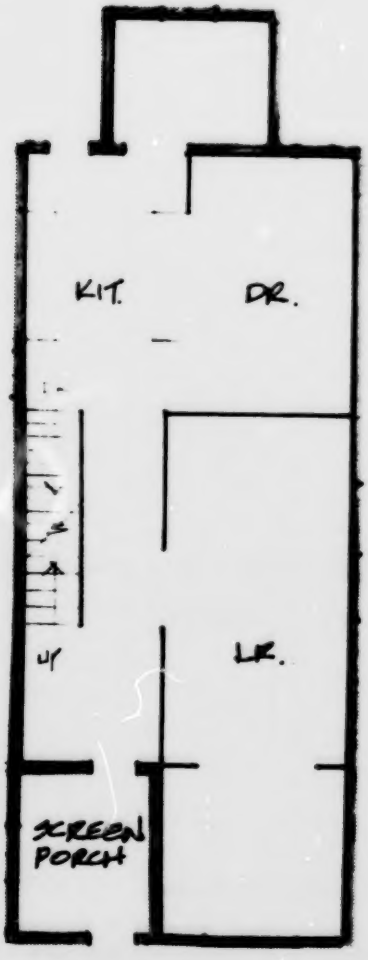


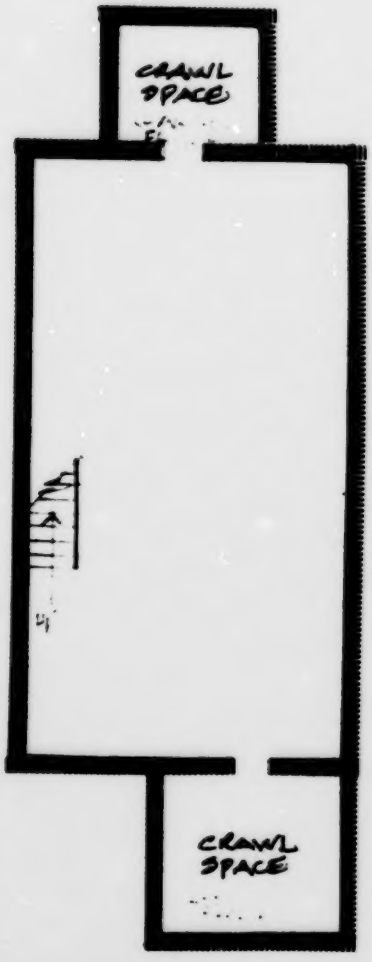

MBR.
BR.
BR.


DEN
BATH
KIT.
LR.
DR.
ENTRY


ENTRY
MBR.
LR.
BR.
BATH
FURNACE
KIT

BATH
MBR.
BR.
BR.


KIT.
DR.
UP
LR.
SCREEN PORCH


CRAWL SPACE
CRAWL SPACE